

DEAMAN User's Manual

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Introduction

Management of elk (*Cervus elaphus canadensis*), mule deer (*Odocoileus hemionus*) and pronghorn (*Antilocapra americana*) populations by the Colorado Division of Wildlife (CDOW) has relied heavily on data collected on each population managed, and use of these data in population models. Four main types of data are used by CDOW biologists to manage these ungulate populations: estimates of harvest by age and sex class, age and sex ratio estimates for the population, age-specific (and sometimes sex-specific) estimates of survival, and estimates of population size. The DEAMAN (Deer, Elk, and Antelope Management) system is a database system to contain the critical data needed by CDOW biologists to manage these ungulate populations.

DEAMAN was developed because of a continuing frustration by myself and others over obtaining the raw data to evaluate various scenarios about deer, elk, and antelope management. The system is based on the philosophy that terrestrial biologists will enter their data into DEAMAN if they get back information that they need, e.g., age and sex ratio estimates and confidence intervals, or population estimates and confidence intervals. Once the data are included in the database, biologists can also obtain tabular and graphical summaries available through DEAMAN. One of the best examples of an analysis that would not have been possible without DEAMAN is provided by White et al. (2001). Collection of the age and sex ratios from file cabinets all around Colorado to perform this analysis would not have been feasible. Because the age and sex ratio data were already in the DEAMAN database, the state-wide analysis was quite feasible.

DEAMAN is developed in the computer language Visual Objects, and operates with any of the modern versions of Windows (95/98/NT/2000/ME/XP) on an Intel-based computer. Procedures are provided for the entry and summarization of data on age and sex ratios, harvest estimates, population estimates, and survival estimates for Data Analysis Units (DAU) and Game Management Units (GMU) of Colorado. Reports can be produced within DEAMAN that include tabular and graphical summaries of the 4 basic types of data. Linked to this database system is a procedure to generate a simple population model in an Excel spreadsheet. The opening menu of DEAMAN, displayed below, provides the entry into these capabilities.



The primary documentation for the DEAMAN software and the methods used is contained herein and the help file that comes with the program. Various published scientific articles (e.g., White and Lubow 2002, White 2000, Bowden et al. 2000, Steinert et al. 1994, White et al. 1989, Bartmann et al. 1986, White 1983, Bowden et al. 1984, Kufeld et al. 1980) describe the estimators and methods programmed in DEAMAN.

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Preliminaries

Installation of DEAMAN on Your Computer

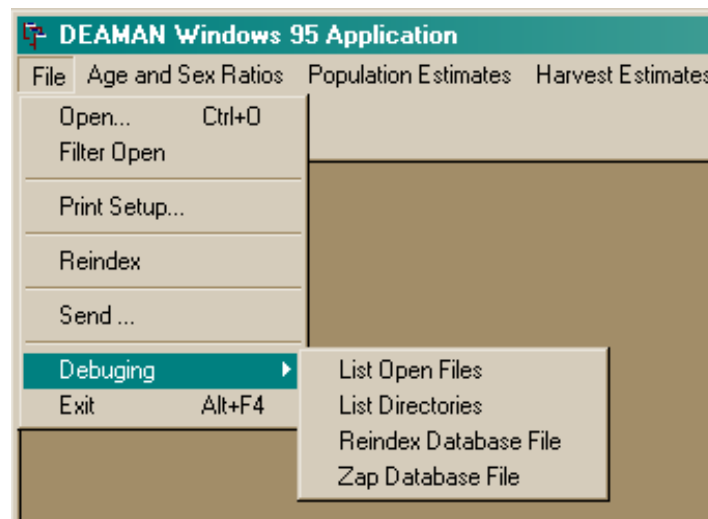
The DEAMAN software can be copied off the Web from the URL:

<http://www.cnr.colostate.edu/~gwhite/deaman/>

The full release of the DEAMAN32 software is available at this site. The setup file that is copied down (Setup.exe) is quite large (>14 Mbytes) because the setup file contains the state-wide data base (as I currently have it). Thus, it is not trivial to copy Setup.exe via telephone modem.

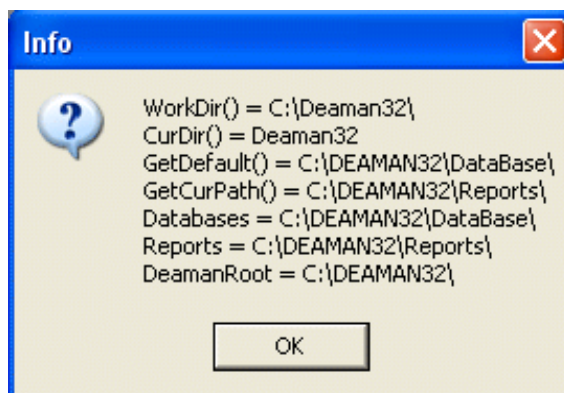
Once you have copied this file to your hard disk, you can execute it via double-clicking the file name from Explorer to install the DEAMAN32 program. The setup program will ask you where to install the program and data. You must install the program in the subdirectory C:\DEAMAN32 for some of the graphics capabilities to work properly. The default subdirectory where Windows will try to install DEAMAN is in the C:\Program Files subdirectory. You must change this option when the program asks where to install DEAMAN.

Data and other information needed to work with the ungulate data are stored in the database subdirectory under the main DEAMAN subdirectory. Usually this location is C:\DEAMAN32\DataBase. The setup program will install a DEAMAN icon on your Desktop. You will then be able to execute DEAMAN just by clicking this icon. To check that you have installed DEAMAN in the correct subdirectory, click the File | Debugging | List Directories menu choices, as shown here.



You will then get a display that shows the subdirectories that DEAMAN thinks it is to be using. In the following example, everything is set to the defaults. Note that the default databases subdirectory is C:\Deaman32\DataBase in the example here.

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Re-installation of DEAMAN

Note that you probably do not want to install a completely new version of DEAMAN over your existing version because ungulate data you have previously entered will be replaced by the files in the new Setup.exe file. To preserve your old data files, rename your DEAMAN32 subdirectory to a new name before you install the new version of the program. After you execute the new program, you may find that some of the data that you thought was present has now disappeared. You can import these data from your old files using the Import capability, described in a section below.

Tip: Do NOT reinstall a full version of DEAMAN if you have already entered data into your old version. Rather, rename your old DEAMAN subdirectory, install the new version, and import your data into the new version.

Viewing Raw Data

To effectively use the DEAMAN database system, you need to know what each of the database files contains. In this section, each of the data files in the DEAMAN system are described. As a preliminary, the following are system files that you should know about.

DATABASE.DBF – Database dictionary: holds the list of data files used in DEAMAN, and provides the list of indexes for each ordering of each data file.

DAU.DBF – DAU dictionary: holds the list of possible DAUs, including the DAU code, species, DAU name, and region, plus the area of the DAU that is surveyed for line transect surveys.

GMU.DBF – GMU dictionary: holds which DAU each GMU is in, with fields containing the DAU for deer, elk, pronghorn, and moose. In addition, 2 additional variables contain the year that these DAU values were first valid, and last valid.

BUGS.DBF – History of bugs fixed in the DEAMAN program.

Available data files

Age and sex counts

AGE_SEX.DBF – Summary of age and sex of animals counted in a particular quadrat or sub-area. In addition, a number of other variables containing summaries needed for calculation of confidence intervals are included in this file.

AGSX_GMU.DBF – Estimates of age and sex ratios by GMU by year.

AGSX_DAU.DBF – Estimates of age and sex ratios by DAU by year.

AGSX_MEMO.DBF – Variables describing counting conditions and procedures for obtaining the counts stored in AGE_SEX.DBF. In addition, another file named AGSX_MEMO.FPT is linked to this database that contains copies of the age and sex memos generated for counts.

AGSXSTRT.DBF – Listing of the strata for quadrat sampling of age and sex ratios. DEAMAN only knows that a DAU is sampled with a quadrat sampling scheme if strata are entered into this file.

Quadrat counts and Population Size

QUADRATS.DBF – Count of animals on a quadrat for each quadrat sampling survey. This file contains the raw counts needed to make quadrat count estimates of population size by DAU by year.

QUADSTRT.DBF – Listing of the strata for quadrat sampling of population size.

POPEST.DBF – Estimates of density and population size, both with confidence intervals, by DAU by year.

Line transect counts

LINETRAN.DBF – Listing of lines flown with the length of line and the group size counted and distance to the group. This file provides the raw data needed to make line transect estimates of population size by DAU by year.

Harvest data

HARVEST.DBF – Estimates of harvest by age and sex class by season by hunter residency status by GMU by DAU by year. This is the largest datafile in DEAMAN because of the multitude of hunting seasons each year.

HARV_GMU.DBF – Estimates of harvest by age and sex class by GMU by DAU by year.

HARV_DAU.DBF – Estimates of harvest by age and sex class by DAU by year.

SEASONS.DBF – List of season codes used in HARVEST.DBF. To understand the seasons stored in HARVEST.DBF, you have to know the meaning of the various acronyms that are explained in SEASONS.DBF.

Survival data

RADIOS.DBF – Characteristics of radio-tracked animals, dates monitored, and their fates, used to construct Kaplan-Meier estimates of survival.

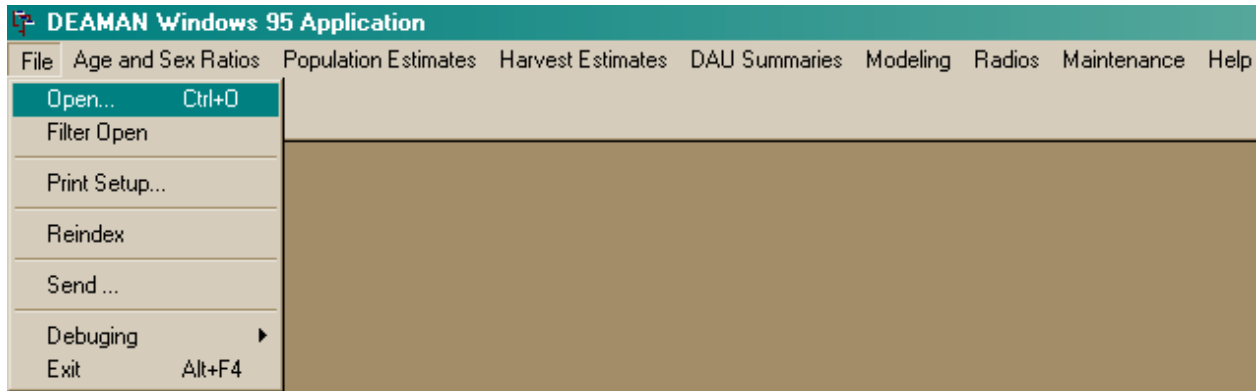
FATECODE.DBF – List of codes used in DEAMAN to describe the fate of an animal in the RADIOS.DBF file.

Opening a data file

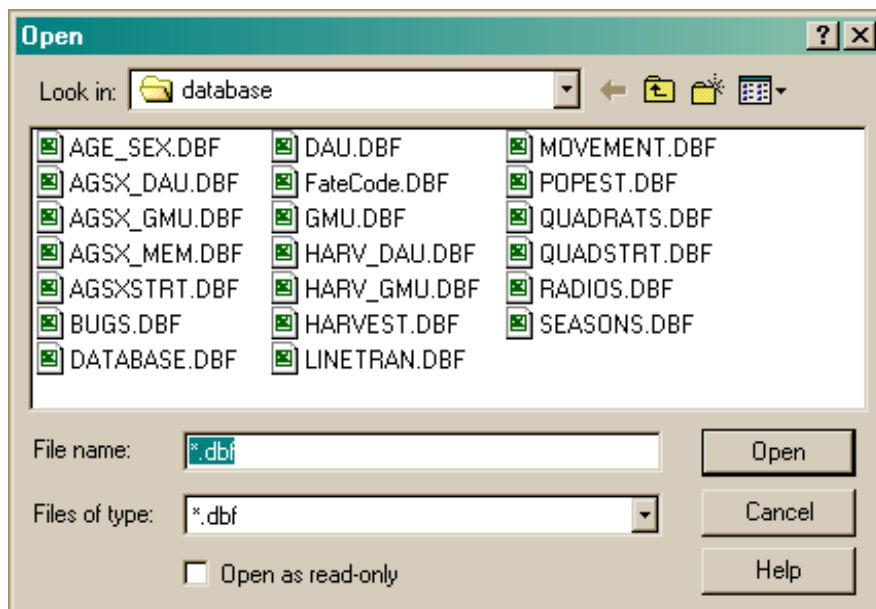
The following sections describe how to open any of the above files to view their contents. The simplest approach is to view the entire file, which is okay for the smaller files. The second section describes how to limit the extent of the data viewed by creating a data filter.

Opening a data file without a filter

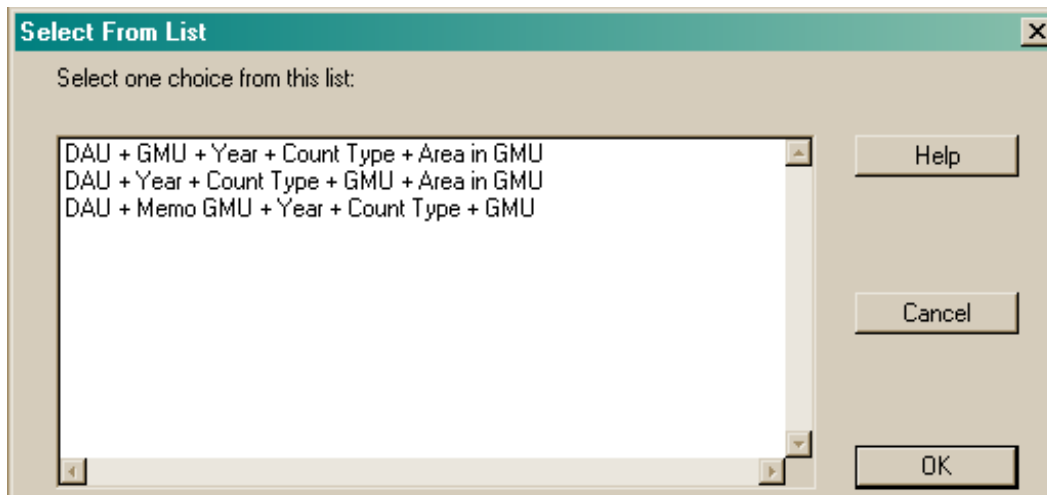
The simplest way to open up a DEAMAN datafile to view the contents is to use the File | Open menu choices highlighted in the following screen display.



These menu choices lead to a dialog box about which file you want to open, as shown in the following screen display.



The default subdirectory (or folder) is the \DEAMAN32\database subdirectory, as shown above. However, you can open up any valid dBase file (file that ends with the DBF extension), and are not limited to just the \DEAMAN32\database subdirectory. To open any file displayed in the list of files, just click the file's name in the Open window above, and then click the "Open" button. For the example to follow, I will open the AGE_SEX.DBF file to demonstrate the power of this feature of DEAMAN. Because AGE_SEX.DBF has multiple index files, meaning that it can be viewed in different orderings, you next get to select from the list of possible orderings. If the file you are interested in does not have multiple orderings, you will not get the following window.



To select the ordering that you prefer, just click on one of the possibilities displayed in the list to highlight it, and click the “OK” button. You have to select an ordering, so not doing anything but clicking “OK” will result in a request to select one of the choices. I will select the DAU + GMU + Year + Count Type + Area in GMU choice (the first one on the above list), and I then get a file browser window for the AGE_SEX.DBF database, ordered by DAU, then GMU, then year, then count type, then area. The top part of this file is shown in the next screen display.

DEAMAN Windows 95 Application - [Browse Database: D:\Deaman32\database\AGE_SEX.DBF]

File Edit Find Record Order Records Query View Window Help

DAU	YEAR	GMU	COUNT_TYPE	MEMO_GMU	AREA_GMU	YEARLING_M	TWOYR_M	ADULT_M	TOTAL_M	YOUNG	FEMALES	UNCLASS	TOTAL	NGRP	SS
A-1	1980	12	POST	12	All of GMU 12	0	0	0	0	0	0	0	1892	1892	1
A-1	1981	12	POST	12	East of Highway 85 (N 1/4)	0	0	0	0	0	0	0	449	449	1
A-1	1981	12	POST	12	West of Highway 85	0	0	0	0	0	0	0	562	562	1
A-1	1981	12	PRE	12	East of Highway 85	0	0	99	99	147	184	0	430	430	1
A-1	1981	12	PRE	12	West of Highway 85	0	0	43	43	15	24	0	82	82	1
A-1	1982	12	POST	12	East of Highway 85 (N 1/4)	0	0	0	0	0	0	0	449	449	1
A-1	1982	12	POST	12	West of Highway 85	0	0	0	0	0	0	0	562	562	1
A-1	1983	12	PRE	12	East of Highway 85	0	0	138	138	196	212	0	546	546	1
A-1	1983	12	PRE	12	West of Highway 85	0	0	19	19	29	41	0	89	89	1
A-1	1984	12	PRE	12	All of GMU 12	0	0	64	64	123	265	0	452	452	1
A-1	1985	12	PRE	12	East of Highway 85	0	0	9	9	53	91	0	153	153	1
A-1	1985	12	PRE	12	West of Highway 85	0	0	22	22	27	50	0	99	99	1

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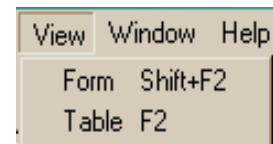
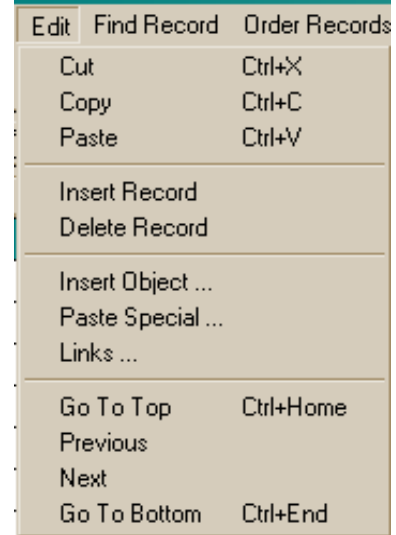
The menu at the top of the screen provides various editing and record selection capabilities. For example, the Edit choice provides the choices shown at the right. You can delete a record from the file, or copy the currently highlighted field, or paste into the currently highlighted field from the clipboard.

The “Find Record” menu choice provides you a dialog window to describe the record you want to find. More details on this dialog window will be provided below in the section about creating filters. The window to describe a record to find is actually the same window as is used to create a filter.

The “Order Records” menu choice gives you the same list of orderings as shown above, so that you can change the order of the records in the file should you discover that you’ve previously chosen the wrong ordering.

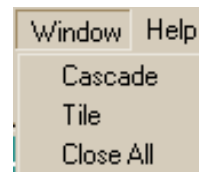
The “Query” menu choice provides a way to re-set the filter of what records will be viewed in the window (but does not change the records in the file). This menu choice allows you to modify a previously created filter (described below), or else to add to an existing filter to be even more selective about what records are viewed.

The “View” menu choice allows you to change the view of the browser window. Two choices are possible, as shown to the right. The Table view is what is displayed above, i.e., the records in the file correspond to rows in a table, and the fields (variables) in the file correspond to columns. You can select the Form view to show just a single record, with each field listed as a separate entry box. A partial example is shown below. Note that the record displayed in the Form view below is the same record as the 7th from the top in the Table view above.



Da <u>u</u> :	<input type="text" value="A-1"/>
Y <u>e</u> ar:	<input type="text" value="1981"/>
G <u>m</u> u:	<input type="text" value="12"/>
C <u>o</u> unt_T <u>y</u> pe:	<input type="text" value="POST"/>
M <u>e</u> mo_G <u>m</u> u:	<input type="text" value="12"/>
A <u>r</u> ea_G <u>m</u> u:	<input type="text" value="West of Highway 85"/>
Y <u>e</u> arling_M:	<input type="text" value="0"/>
T <u>w</u> oyr_M:	<input type="text" value="0"/>
A <u>d</u> ult_M:	<input type="text" value="0"/>
T <u>o</u> tal_M:	<input type="text" value="0"/>
Y <u>o</u> ung:	<input type="text" value="0"/>
F <u>e</u> males:	<input type="text" value="0"/>
U <u>n</u> class:	<input type="text" value="562"/>
T <u>o</u> tal:	<input type="text" value="562"/>
N <u>g</u> rp:	<input type="text" value="1"/>

The “Window” menu choice allows you to arrange windows on your screen in a cascading view, or in a tiled view. This feature is handy when you have several file browser windows open at once, which you can do by repeatedly going to the File | Open menu choice and opening up files.




Also at the top of the file browser window are a set of task buttons that provide short cuts to the menu choices. To figure out the function of a particular task button, just place your cursor on the button and wait a second. A message will appear explaining the button's function. For example,



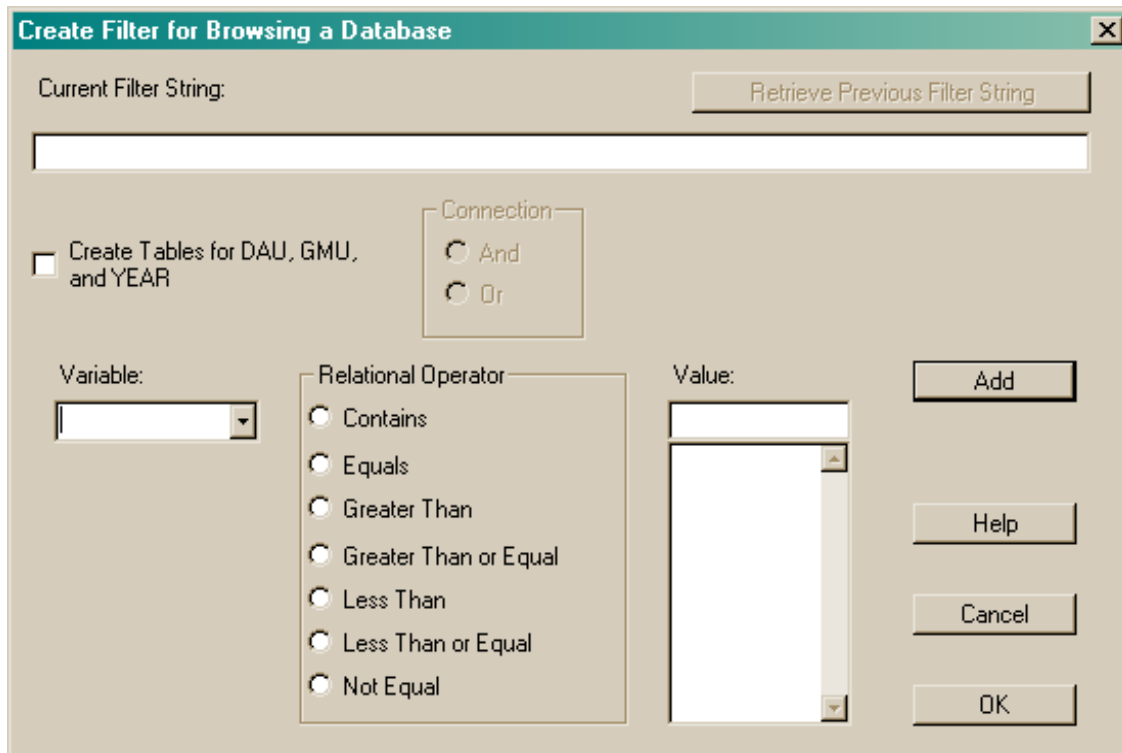
shows the button with the cursor on (actually under) it moves you to the bottom of the file. Do the same with the rest of the buttons on the task bar to figure out their function.

Creating a filter to view a subset of the data

Creating a filter to filter the contents of a file you are opening provides you the ability to open a file and only view the records you are interested in, thus not causing you to have to sort through hundreds of records to identify just a few problem records. The filter window is a powerful feature of the file browser, and is a necessary function in DEAMAN.

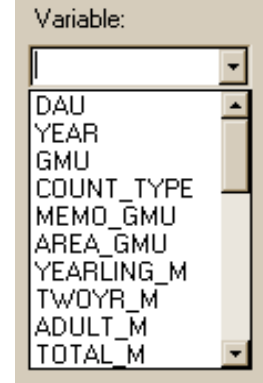
 Tip: The same dialog window is used to create a filter string for opening a file, to locate a specific record that meets a set of criteria, or to create a query within the file browser. Thus, you can practice with this window from within the file browser, and don't have to use it from just the File | Filter Open menu choices.

The window used to create a filter depends on what file is being opened, and what variables or fields are in this file. Lets consider again the AGE_SEX.DBF file. Suppose we only want to see records for DAU E-6 for the year 2000. We select the File | Filter Open menu choices from the main menu of DEAMAN, and eventually are asked to create a filter with the following window.

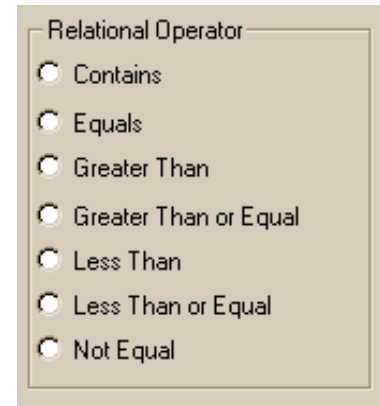


The dialog box titled "Create Filter for Browsing a Database" features a teal header bar with a close button (X). The main area is light beige. At the top, there is a label "Current Filter String:" followed by a large empty text box and a button labeled "Retrieve Previous Filter String". Below this, on the left, is a checkbox labeled "Create Tables for DAU, GMU, and YEAR". To its right is a "Connection" group box containing two radio buttons: "And" and "Or". Further down, there is a "Variable:" label next to a dropdown menu. To the right of the dropdown is a "Relational Operator" group box with seven radio buttons: "Contains", "Equals", "Greater Than", "Greater Than or Equal", "Less Than", "Less Than or Equal", and "Not Equal". To the right of the operators is a "Value:" label next to a text box with a scroll bar. On the far right, there are four buttons stacked vertically: "Add", "Help", "Cancel", and "OK".

The place to start in this dialog window is in the “Variable” box, on the left side of the window. The right arrow on this box will provide you with a scrollable list of the variables in the file you are opening. For the AGE_SEX.DBF file, this list is long, because of all the summary variables required for estimating confidence intervals. A portion of the screen is shown to the right to see what happens when you click on the down arrow to the right of the box. You can now click on the name of the variable you want to select. So for our example, we might first select the variable “DAU”, because we want only records from DAU E-7. When we click on this variable, the box above fills with the variable name DAU, and we are ready for the next step. Note that the list of variables is in a scrollable box – many more are available further down in the box shown.



Next you specify what relational operator you want between the variable you just selected and the value that you will soon enter. The set of possible choices are shown at the right. Click on the radio button to select an operator. The “Contains” operator is particularly useful for selecting all the records for a single species, e.g., ask for the DAU fields that contain “D” to get all deer records. The rest of the operators are pretty obvious. However, you can use the greater than and less than operators to obtain results with character fields, not an obvious procedure. With character fields, these operators use the sorted order of the character fields, and thus still work.



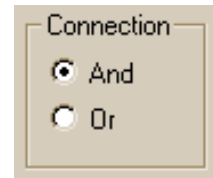
The third step is to specify the value you want in the expression. Use the tab key to move to the value box, or else click on the box with your mouse. The most common mistake is that spaces are embedded in your variable value. For example, requesting year equal to “2000” will not give you any records, because of the space before the “2”. Likewise, be careful how you specify a DAU value. The letter in the DAU value has to be a capital, and no spaces can be embedded in the value.

At this point, it is worth discussing the function of the check box above the Variable entry box, shown at the right. This check box allows you to build a list of all the potential values of the variable you’ve selected in the Variable entry box for use in the Value entry box. The possible values will appear below the Value entry box. The problem with checking this box is that it takes too long to compile the list of possible values for any reasonable database. So, I tend not to use it, but beginners may be more patient than me, and want to see the list of values that are available to be opened in the database.



Once you enter the appropriate value, you then have to tab to the Add button and hit the Enter key, or else click the Add button. Until you do this, the expression that you have created is not added to the “Current Filter String” box at the top of the Window. The Current Filter String entry box provides you with a record of what the filter expression you’ve created looks like. In addition, you can edit the expression to change the field variable, operator, or value if you know how to create filter expressions in dBase or other languages.

After you’ve clicked the Add button once, the set of options for connections between expressions lights up. Two possibilities can be selected from. The first is an “And” connection, and is the default. The best way to understand these connections is by example. If I’ve asked for DAU to equal D-7, left the default connection to “And”, and then requested year to equal 2000, I’ll get the following in the Current Filter String:



Current Filter String:
DAU == 'D-7 ' .and. YEAR == '2000'

This request will select all the records with DAU equal to D-7 AND year equal to 2000. However, if I want either DAU equal to D-7 OR year equal to 2000, I would want to click the Or button before I specified the expression for year. I doubt that you would want such a request, so will now illustrate a reasonable request for the Or button. Suppose you want either DAU D-7 or D-9 for the year 2000. Your approach should be to first build the expression for DAU D-7, then use the Or connect to build the expression for DAU D-9, and then use the And connection to build the expression for year equal to 2000. Unfortunately, what you would get if you don’t edit the Current Filter String entry box is the following:

Current Filter String:
DAU == 'D-7 ' .or. DAU == 'D-9 ' .and. YEAR == '2000'

This filter will result in all of the records with DAU equal to D-7 and only the records for DAU equal to D-9 where year equals 2000. To get the request you originally wanted, you need to add some parentheses to the Current Filter String expression to make the And connection apply to both DAUs D-7 and D-9. The following shows the correct filter expression.

Current Filter String:
([DAU == 'D-7 ' .or. DAU == 'D-9 ']) .and. YEAR == '2000'

To add these parentheses, just click the Current Filter String entry box at the location where you want to add the paren, and enter it via the keyboard.

The final control on the Create Filter String window that is useful is the “Retrieve Previous Filter String” button. This button is not available the first time you open up the Create Filter String window in a DEAMAN run, because you have not created a previous filter string. Once you have created a filter string during a DEAMAN run, the button will become available to retrieve the previous filter expression. With this button, you can go back and modify a complicated expression directly in the Current Filter String entry box, rather than creating it from scratch each time.

Data Entry

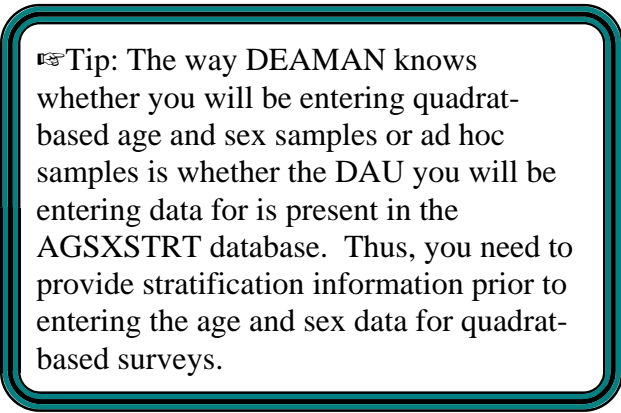
Data must be entered into DEAMAN on age and sex ratios, population estimation, and survival before any information is available from the system. The following sections explain how data are collected and entered for these 3 types of population parameters.

Age and sex ratio data

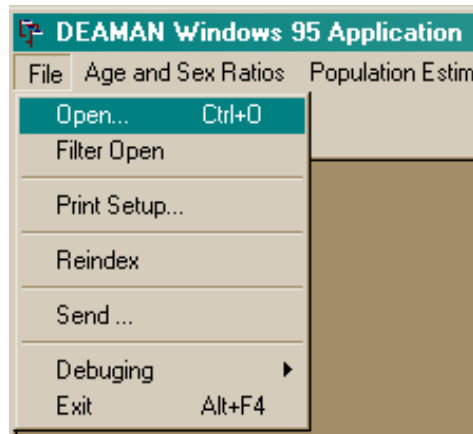
In DEAMAN, age and sex ratio data are assumed to be collected via aerial surveys that reflect the age and sex ratios for the entire DAU. Two types of surveys are allowed in DEAMAN. The first is the more rigorous, preferred approach of classifying animals on randomly selected quadrats. This sampling scheme provides unbiased estimates of sex and age ratios given that quadrats are properly selected for survey, and no classification errors are made. Stratification of the area to be sampled is allowed and is preferred to provide better sample coverage of the area.

Age and Sex Quadrat Stratification File

Before data can be entered for age and sex surveys with stratified quadrats, the AGSXSTRT.DBF file must be modified to provide necessary information on the sampling scheme. The only way that DEAMAN knows if you want to enter age and sex data from quadrats or from ad hoc surveys is by whether the stratification information is entered in the AGSXSTRT.DBF file. To modify this file, select the File | Open menu choice as shown in the following screen.

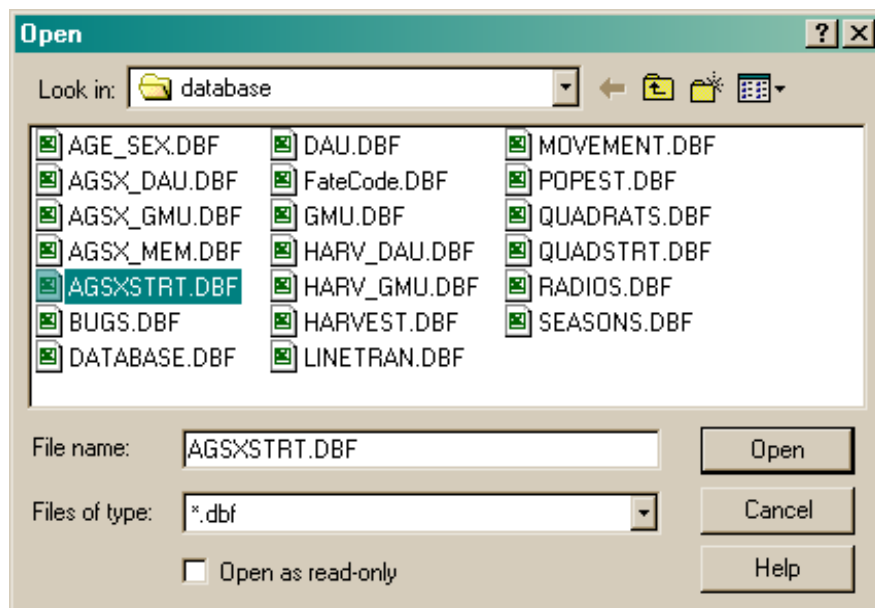


Tip: The way DEAMAN knows whether you will be entering quadrat-based age and sex samples or ad hoc samples is whether the DAU you will be entering data for is present in the AGSXSTRT database. Thus, you need to provide stratification information prior to entering the age and sex data for quadrat-based surveys.



Then select the file named AGSXSTRT.DBF from the Open dialog box that appears. That is the highlighted file in the following example. The default subdirectory for the File | Open menu choice is the C:\DEAMAN32\database subdirectory, where data and other information are stored.

Tip: The file browser window can be switched back and forth between a table view and a form view, where a single record is shown on the screen. Two buttons on the task bar will make the switch, or else menu choices under View.



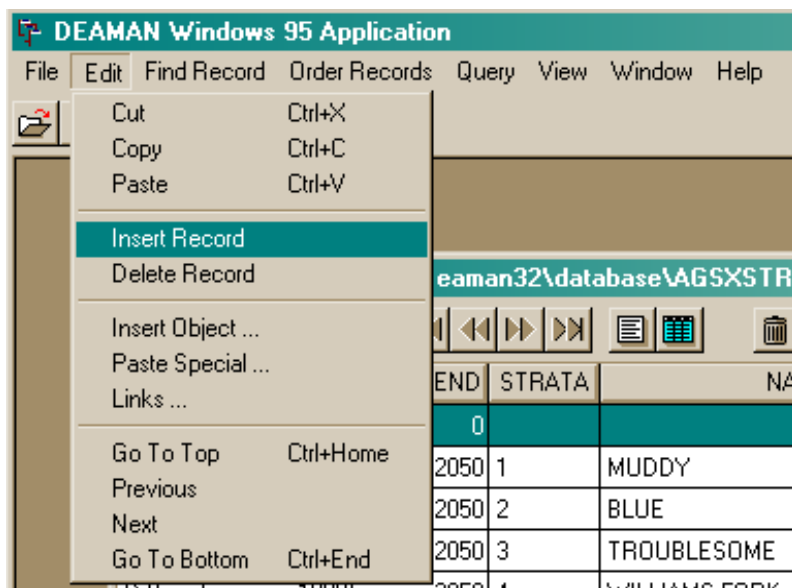
An example for DAU D-9 is shown below. The YEAR_STRT and YEAR_END variables define the year that the age and sex stratification begins and ends. Typically, I assume that the end is the year 2050, just to be sure that the stratification scheme does not expire before the user does. The STRATA variable lists the strata label, in this case just the numbers 1, 2, 3,

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and 4, for the 4 strata. The strata are also named so that the user can remember the location of each. Next is the quadrat size that is surveyed (QUADSIZE) in square miles. Finally the size of the strata in square miles is specified in the variable STRATSIZ.

DAU	YEAR_STRT	YEAR_END	STRATA	NAME	QUADSIZE	STRATSIZ
D-9	1998	2050	1	MUDDY	1.00	179.00
D-9	1998	2050	2	BLUE	1.00	82.00
D-9	1998	2050	3	TROUBLESOME	1.00	82.00
D-9	1998	2050	4	WILLIAMS FORK	1.00	75.00

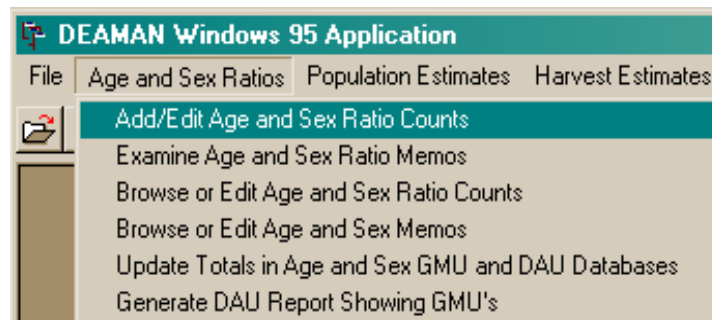
To add stratification data to this file, you must open it with the File | Open menu choice, and select the AGSXSTRT.DBF file. Then, select the Edit | Insert Record menu choices as shown here. You can then fill in the new blank record with the information needed for one stratum. You will have to repeat the process for each of your age and sex strata.



The alternative survey approach is to classify animals where they are found, without any attempt to randomly select animals. This approach is likely to lead to biased estimates of the age and sex ratios, particularly sex ratios, because males and females are spatially segregated (particularly elk), with females generally in larger groups. As a result, females are more likely to be encountered than males, so that the sex ratio estimate is biased low for males. To enter data for this ad hoc sampling scheme, no stratification information is needed, as described above for the more rigorous sampling approach.

Age and Sex Ratio Data Entry

To enter age and sex ratio data, select the Age and Sex Ratios | Add/Edit Age and Sex Ratio Counts menu choices, as shown here.




The result will be a dialog box shown below where you first specify the DAU. DAU names must start with an upper case letter (D for deer, E for elk, A for antelope, M for moose, S for sheep, or G for goat), followed by a hyphen and the DAU number type of age and sex ratio survey. The down arrow on the left of the DAU entry box allows you to have a list presented from which you can select the DAU by clicking on it.

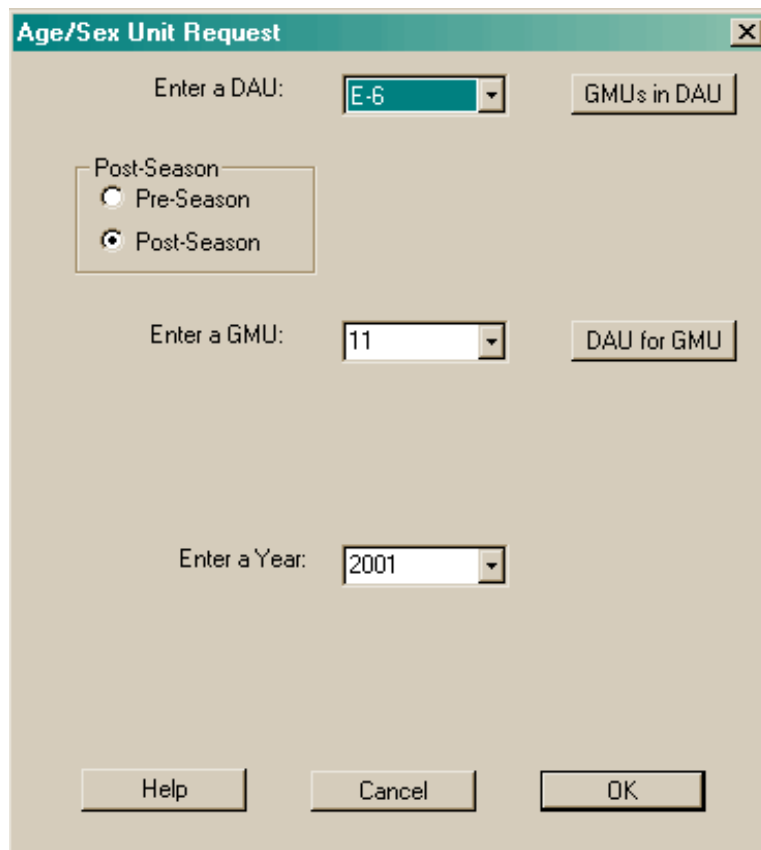
Other information that you specify in this dialog box is the count type, i.e., whether pre-season (before hunting season) or post-season (after the hunting season). You select the type of count by clicking the appropriate button.

Next you specify the GMU where the age and sex ratio were collected. Given that you've specified the correct DAU in the first entry on the window, then clicking the arrow to the right of the GMU box will give you a list of GMUs that are in the DAU.

Tip: If the proper list of GMUs does not appear when you click the arrow to the right of the GMU box, 1) make sure you correctly entered the DAU, and if so, check to see that you have remembered correctly what GMUs and DAUs go together with the GMU or DAU check buttons.

Last, select the correct year for the age and sex data that you are about to enter. The year in DEAMAN is the biological year. That is, age and sex ratio counts are performed generally in December for deer, but occasionally not until January for elk. As an example, if counts are made in January of 1988, the YEAR would be 1987. If counts are made in December of 1987, the YEAR would be 1987. YEAR pertains to the year at the start of the winter, not the end of the winter. Another way to remember YEAR is that the biological year is the same as the year of the harvest. Think of the year of harvest as the start of the biological year, or that post-season age and sex ratios are associated with the previous harvest.


 Tip: The year in DEAMAN pertains to the year of the start of the winter, which is the year of the previous fall's harvest.

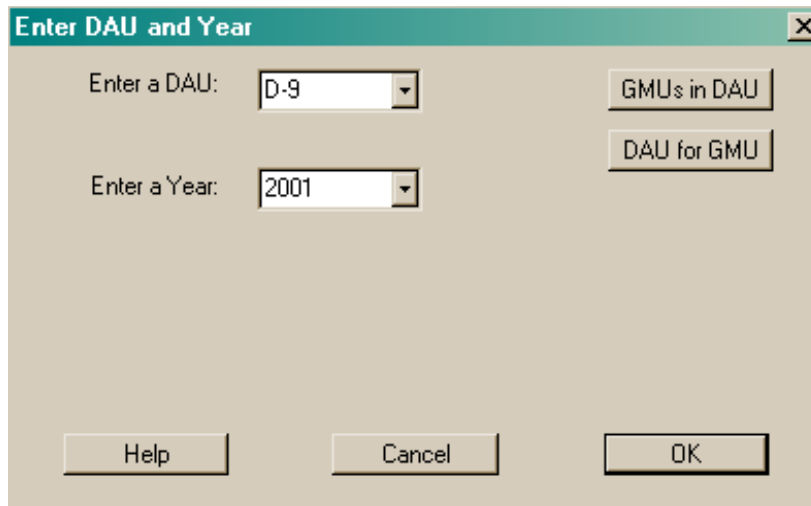


The dialog box is titled "Age/Sex Unit Request" and contains the following fields and controls:

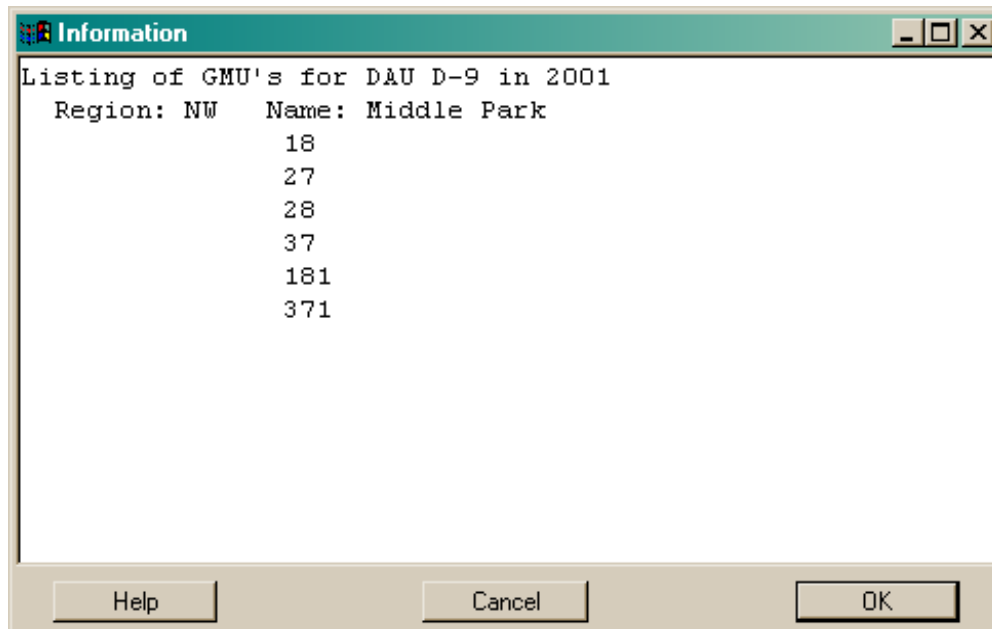
- Enter a DAU:** A dropdown menu showing "E-6". To its right is a button labeled "GMUs in DAU".
- Post-Season:** A group box containing two radio buttons: "Pre-Season" (unselected) and "Post-Season" (selected).
- Enter a GMU:** A dropdown menu showing "11". To its right is a button labeled "DAU for GMU".
- Enter a Year:** A dropdown menu showing "2001".
- At the bottom are three buttons: "Help", "Cancel", and "OK".

The most common frustration with entering data is remembering what DAU and GMUs are associated. Two additional buttons are available to help you remember which GMUs belong to what DAU. Clicking the “GMUs in DAU” button results in the following display. You enter the DAU and year for which you want the list of GMUs that belong in the specified DAU.

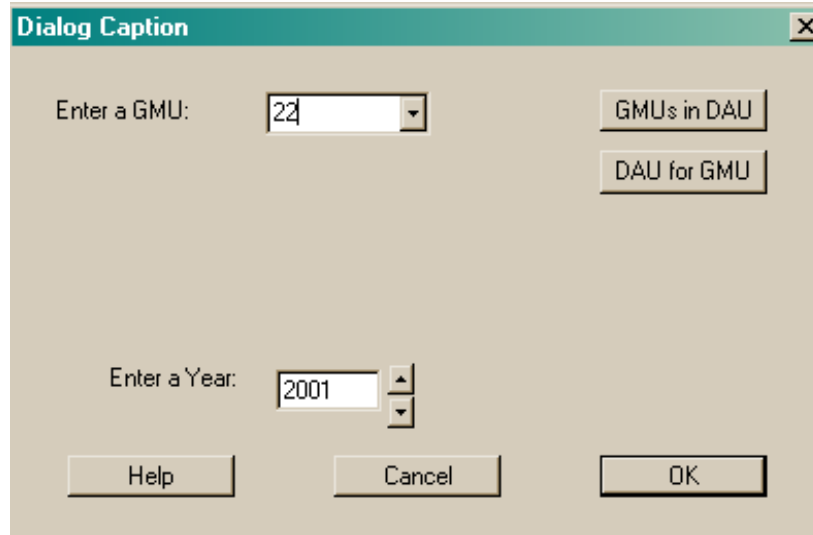
 **Tip:** All dialog screens in DEAMAN should have functional HELP buttons. If you don't get the help you are wanting, copy the help screen name and contents to an email, and tell me what you wanted to know so that I can update the help file. Only the users can really write the help file.



By clicking the “OK” button on the above display, you would receive the following output for DAU D-9 for the year 2001. The result from the above request would be as follows. To close the information box, click “OK” or else “Cancel”.

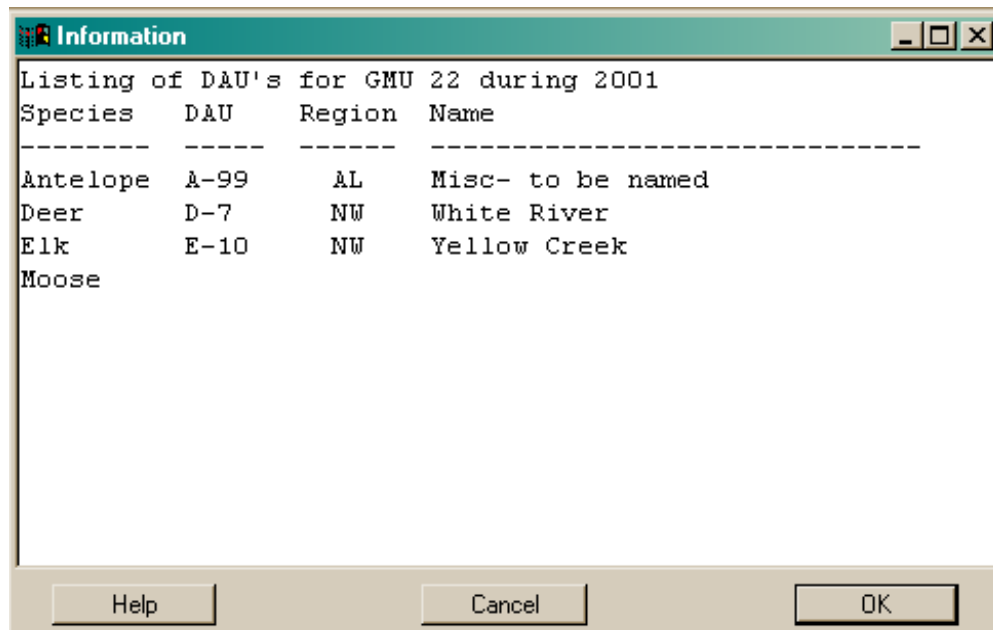


The other button to help you remember which DAU goes with a GMU is the “DAU for GMU” button. Clicking this button results in the request for a GMU for which you want the DAUs that it belongs to. The following will request the DAUs that GMU 22 is part of.



The above request results in the following information.

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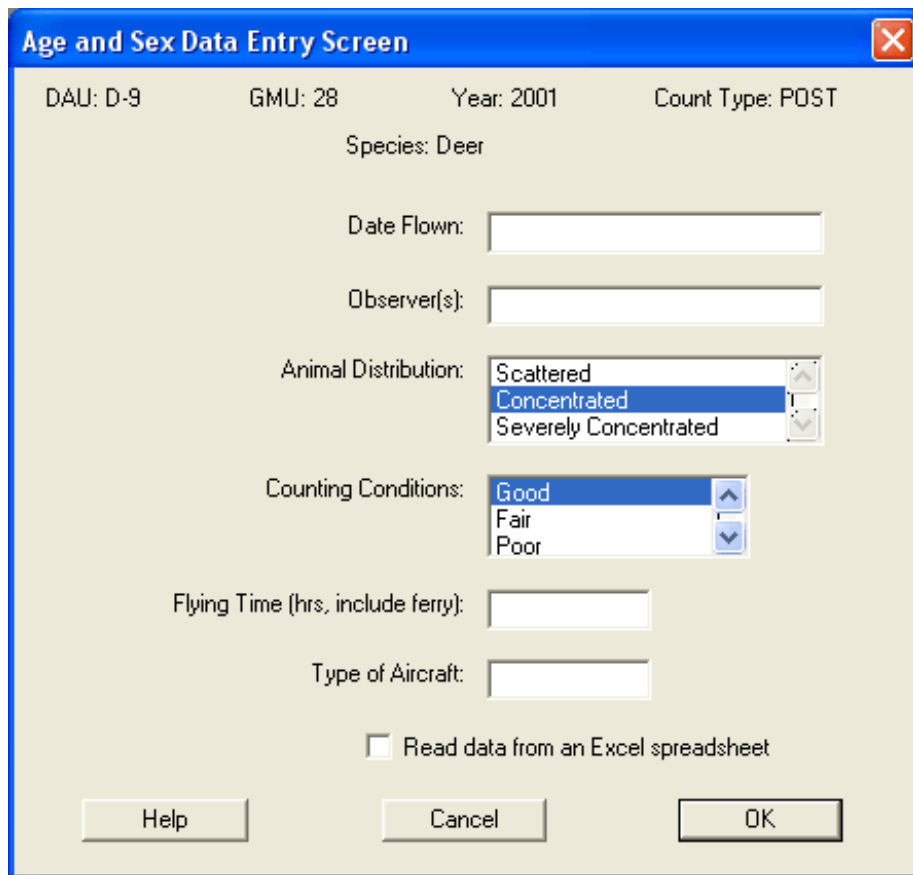


When age and sex ratio data are to be entered, some initial information is required that is appropriate for the survey that was conducted. This information is:

- ◆ Date the survey was flown, e.g., December 21, 2002;
- ◆ Name(s) of observers;
- ◆ Animal concentration, selected from the list: Scattered, Concentrated, Severely Concentrated;
- ◆ Counting conditions, selected from the list: Good, Fair, Poor;
- ◆ Flying time in hours, including ferry time; and
- ◆ Type of aircraft, e.g., Bell Soloy, Piper Cub, etc.,

as shown in the dialog box below. This information is stored in the AGSX_MEM.DBF database to provide documentation on the type and quality of the survey conducted, and will be appear on the age and sex memo that is generated once all the data have been entered.

In addition, a check box at the bottom of the dialog box allows you to have the data read from an Excel Spreadsheet file. If this box is checked, you should have an Excel spreadsheet put together that lists the data for each of the groups observed. Details on how to format the Excel spreadsheets will be given after the specifics of direct data entry are given.



The dialog box is titled "Age and Sex Data Entry Screen" and features a standard Windows-style title bar with a close button (X) in the top right corner. The main area contains several input fields and dropdown menus. At the top, there are four labels: "DAU: D-9", "GMU: 28", "Year: 2001", and "Count Type: POST". Below these is a label "Species: Deer". The "Date Flown:" field is a text box. The "Observer(s):" field is a text box. The "Animal Distribution:" field is a dropdown menu with three options: "Scattered", "Concentrated" (which is currently selected and highlighted in blue), and "Severely Concentrated". The "Counting Conditions:" field is a dropdown menu with three options: "Good" (selected and highlighted in blue), "Fair", and "Poor". Below these are two more text boxes: "Flying Time (hrs, include ferry):" and "Type of Aircraft:". At the bottom of the main area is a checkbox labeled "Read data from an Excel spreadsheet", which is currently unchecked. At the very bottom of the dialog box are three buttons: "Help", "Cancel", and "OK".

Once these values have been entered, click the “OK” button to proceed. By clicking the “Cancel” button, you can cancel data entry and return to the main menus. The “Help” button will provide you with some assistance in what is being requested.

After clicking “OK” and NOT checking the Excel spreadsheet option, the following dialog box will then appear on your screen. The box may only be partially visible. To make the entire box visible, first make sure that the entire DEAMAN application window is full size – you do this by clicking the box next to the X in the upper right corner of the window. Next, click the box next to the X in the upper right corner of the age and sex data entry window. The box shown below is for entering data collected on quadrats. This dialog box is highly interactive.

Age and Sex Quadrat Data Entry

Data to be entered in the database for the following survey:
 DAU: D-99 GMU: 999 Year: 2001 Count Type: POST
 Primary GMU of flight:
 Species: Deer
 Date Flown:

GMU of Counts: Strata: Quadrat:

Current Group

Females: 2-Year Old Males:

Young: Adult Males:

Yearling Males: Unclassified:

Groups Entered so far for Current Quadrat:

Group:	Females:	Young:	Yearling M:	Twoyr M:	Adult M:	Unclass:

First, you must specify the GMU of the counts (999, a fake GMU, in the example above). The arrow on the right side of the GMU entry box will provide a list of the valid GMUs you can select from for the DAU originally specified. Then, specify the strata, selecting from one of the valid strata that you entered in the AGSXSTRT.DBF file. Finally, specify the quadrat identifier. No quadrats will be available because there is not a list of quadrats associated with each strata.

Once the identifying information has been entered, you are ready to enter your classification numbers. For each group of animals encountered in the quadrat, enter the number of females (age 1+), young, yearling males, 2-year old males, adult males, and also any animals not classified. You can use the Tab key to quickly shift the cursor through these data entry boxes. Blank boxes are treated as zeros, so you don't have to enter zeros. When you hit the Tab

key after entering (or skipping through) the unclassified box, the “Add This Group to Data Table” button will be highlighted. Hitting the “Enter” key, or clicking this button, will add the data entered into the table just below. Repeat this process until all the groups for the quadrat have been entered.

If you make a mistake, you can correct the entry in the table below by highlighting the value with your cursor by clicking the value, and then entering the correct value. If you want to delete the entire row from the table, just click the “Delete Highlighted Record” button.

Once you have entered ALL the data for the quadrat, you are ready to add the summarized quadrat data to the AGE_SEX.DBF file in the DEAMAN database. Just click the “Add This Quadrat to Data File” button that is just below the table.

If you are unsure of what quadrats you have already entered, or just want to check on your progress, click the “List Data in Data File” button, and you will get a summary like the following. Note that the columns are wrapped around the end of the line because of the width of the window.

Information

Areas Entered Into the Age and Sex Counts Database

DAU: D-9 Year: 2001 Count Type: POST

Area	Ad. Males	Females	Young	Unclass.	Yrlg. Males	2-Yr Males
GMU: 18						
T-17					0	0
0	0	0	0			
T-20					4	11
5	7	4	0			
T-34					5	8
3	18	10	6			
T-35					1	3
1	12	8	1			
T-46					0	0
0	0	0	0			
T-60					0	0
0	0	0	0			
T-63					2	2
3	71	20	10			
T-68					0	0
0	0	0	0			
T-7					1	1
1	13	8	2			

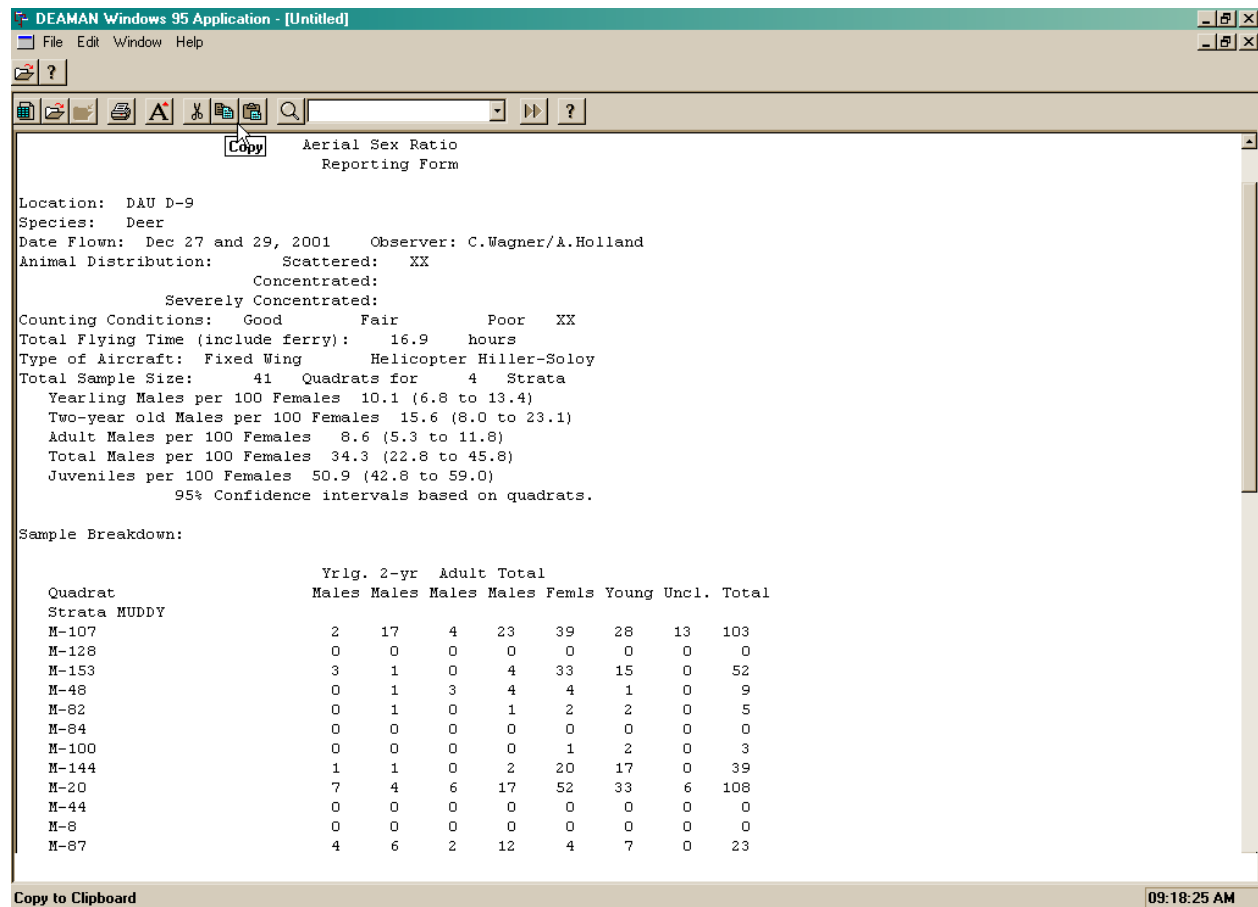
Help Cancel OK

Once all the quadrats have been entered, and data for each quadrat have been added to the AGE_SEX.DBF file, you are ready to generate the age and sex summary memo. Just click the “Generate Memo and Close” button to generate the memo, and close out data entry. Don’t generate the memo until all the data have been entered. The key parts of the age and sex memo for DAU D-9 in 2001 looks like the following.

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This memo can be printed by clicking on the Print button above the memo (not shown above because of lack of space), or by selecting File | Print from the window's menu. Another useful option is to copy the memo into the clipboard, which can be done by clicking on the window and highlighting all the text by holding down the left mouse button, and then hitting the Ctrl-C keyboard button, or else clicking on the Copy button above the memo.

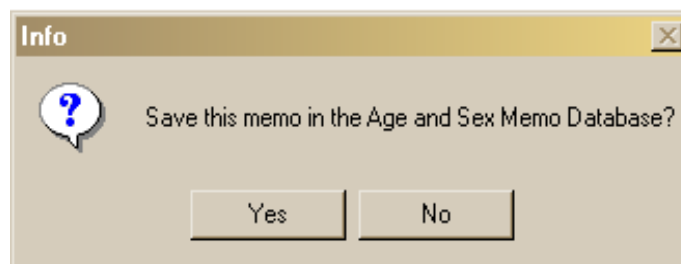
To see what the function of each of the buttons are above the window, just put your cursor on the button and leave it for a second, e.g., the display shown below.



Once the text has been copied to the clipboard, you can then open up a Word document, and paste this text into the document for further editing, so that professional-looking memos can be generated and sent to individuals needing to know your results.


When you close the memo window by clicking on the lower X on the upper right corner of the memo window, you will be asked if you want to save the memo in the Age and Sex Memo Database. Click the “Yes” button to save the memo. This means that the memo will be available for browsing directly from DEAMAN, and also that it will be exported with the age and sex data, a process described below.

 Tip: Most windows in DEAMAN can be expanded to full screen size by clicking the Box in the upper right corner. If a particular window does not expand, make sure that the main DEAMAN window has been expanded to full screen. You can also drag the edge of most screens to expand their size, but not expand them to full screen.



Data entry for ad hoc surveys where no defined sampling frame is used is similar to data entry for quadrats. The main difference is that a sub-area is defined as part of the survey, so that the age and sex classification counts can be related back to portions of the DAU. Instead of specifying a stratum and a quadrat, you must specify the “Specific Area of Counts”. Typically, geographic areas are specified, e.g., Antelope Knob, Bitter Brush SWA, etc.

Once all the animal groups are entered, you click the “Add This Area to Data File” button below the summary table. Once all the sub-areas are entered, click the “Generate Memo and Close” button to produce a memo summarizing the classifications. Otherwise, data entry for the ad hoc surveys is identical to data entry for the quadrat surveys.

 Tip: You should not enter more data for a subarea than you are willing to re-enter if you discover a mistake later after all the data have been entered. Instead, break up your areas into small units that are easier to verify and check.

Age and Sex Count Data Entry

Data to be entered in the database for the following survey:
 DAU: D-7 GMU: 11 Year: 2000 Count Type: POST
 Primary GMU of flight: 11
 Species: Deer
 Date Flown: December 14, 2000
 Observer(s): Bill deVergie
 Animal Distribution: Concentrat
 Counting Conditions: Fair
 Total Flying Time (include ferry): 3.0
 Type of Aircraft: Hiller Soley

GMU of Counts: Specific Area of Counts:

Current Group

Females: 2-Year Old Males:
 Young: Adult Males:
 Yearling Males: Unclassified:

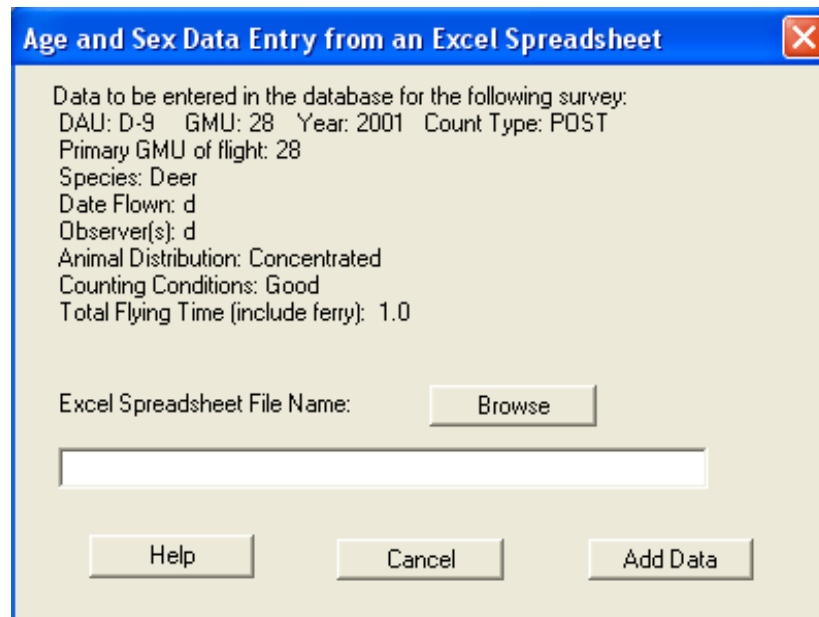
Groups Entered so far for Current Area:

Group:	Females:	Young:	Yearling M:	Twoyr M:	Adult M:	Unclass:

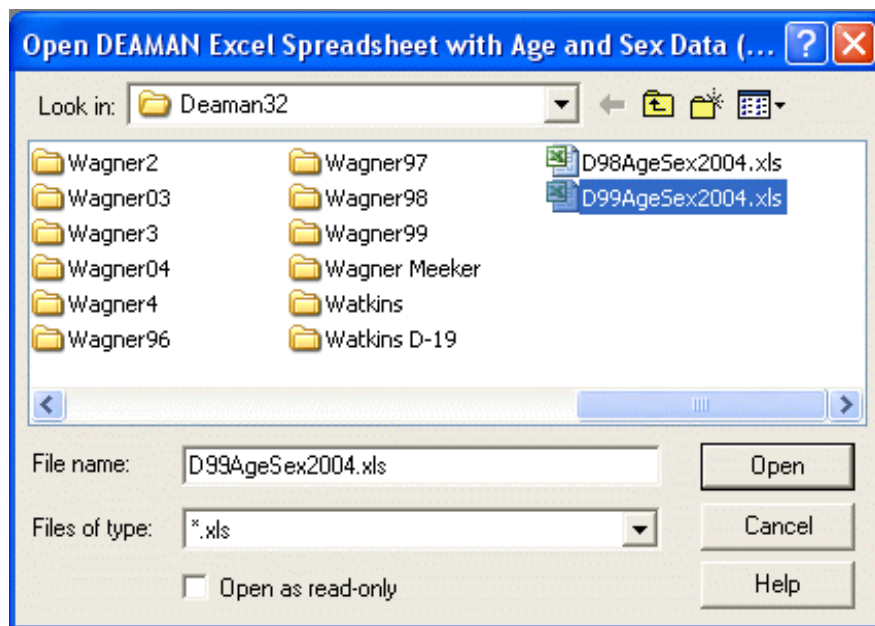
One issue is whether to enter the data for each GMU of a DAU separately, and produce a memo for each, or whether to combine the data into only one memo for the DAU. I would recommend entering the data for DAUs with quadrat surveys as one memo, because the GMUs are generally part of defined strata, and the sampling plan is design from the entire DAU, not specific GMUs. However, for ad hoc surveys, I suggest that data be entered via GMU and each GMU has an associated memo. The main reason for doing each GMU separately is that you can then retrieve a memo for each GMU. Otherwise, you have to guess which GMU was used as the “Master” GMU to find the memo associated with a specific GMU.

Because the data entry process to enter each of the groups observed can be pretty tedious, the option of recording data into an Excel spreadsheet has been developed. If you check the box specifying an Excel spreadsheet, the following dialog box appears.

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You are being asked to enter the name of the Excel spreadsheet file from which data are to be read. Normally, you should click the Browse button to let Windows help you locate the file. Navigate to the location of the file, and click on it to open it.



Once you have found the file, the file name in the previous dialog box will be filled in, and you can click the "Add Data" button to proceed.

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The format of the Excel files has to be very specific, and is somewhat unique for whether the data are for a DAU with a stratified random sampling plan for age and sex ratios, or for the traditional approach lacking a sampling plan. For a DAU with a sampling plan, the following trivial example illustrates the format.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	DAU	YEAR	GMU	COUNT_TYPE	STRATA	QUADRAT	YEARLING_M	TWOYR_M	ADULT_M	FEMALES	YOUNG	UNCLASS	GROUP
2	D-99	2004	999	POST	1	Quadrat 1	0	0	0	7	5	0	1
3	D-99	2004	999	POST	1	Quadrat 1	2	4	6	8	10	12	2
4	D-99	2004	999	POST	1	Quadrat 1	2	2	0	2	0	0	3
5	D-99	2004	999	POST	1	Quadrat 1	0	0	0	5	0	0	4
6	D-99	2004	999	POST	1	Quadrat 2	2	4	6	8	10	12	1
7	D-99	2004	999	POST	1	Quadrat 3	0	0	1	5	4	0	1
8	D-99	2004	999	POST	1	Quadrat 4	1	0	0	1	2	0	1
9	D-99	2004	999	POST	1	Quadrat 5	0	0	0	0	0	0	1
10	D-99	2004	999	POST	2	Quadrat 21	1	2	3	4	5	6	1
11	D-99	2004	999	POST	2	Quadrat 21	1	2	3	4	5	6	2
12	D-99	2004	999	POST	2	Quadrat 21	1	2	3	4	5	6	3
13	D-99	2004	999	POST	2	Quadrat 22	1	2	3	4	5	6	1
14	D-99	2004	999	POST	2	Quadrat 22	1	2	3	4	5	6	2
15	D-99	2004	999	POST	2	Quadrat 22	1	2	3	4	5	6	3

Note the headings at the tops of the 13 columns. These headings have to be exactly as shown for DEAMAN to know that this is a spreadsheet with age and sex ratio data. Each quadrat is entered and each group observed in a quadrat contributes a row to the spreadsheet. So, 4 groups were observed on Quadrat 1, 1 group on Quadrat 2, 1 group on Quadrat 3, etc. Also note that quadrats counted where no animals were observed are also entered, e.g., Quadrat 5 in the above example. The DAU, YEAR, and COUNT_TYPE variables will be constant for the spreadsheet, i.e., the values will be the same for all rows. The only valid values of COUNT_TYPE are POST or PRE, i.e., post-harvest or pre-harvest. The values of the STRATA variable must match the values in the AGSXSTR database.

The definitions of the columns containing animal counts are obvious:

YEARLING_M – yearling males

TWOYR_M – two-year old males

ADULT_M – adult males

FEMALES – females

YOUNG – young of the year, i.e., calves or fawns, and

UNCLASS – number of animals not classified.

The GROUP column provides a sequence number of the groups within a quadrat, but is not actually used.

For a DAU without a sampling plan, the following format must be followed. The only difference from the above spreadsheet is that the STRATA column is now labeled as MEMO_GMU, and the QUADRAT column is now labeled as SUB_AREA. In this case, areas

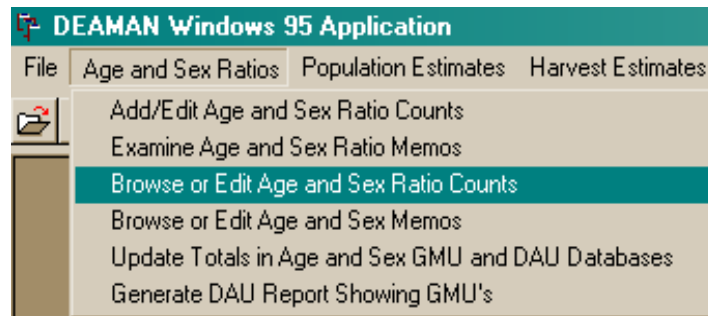
where no deer are observed are not entered into the spreadsheet, i.e., each row must have a non-zero value for one of the 6 columns providing animal numbers.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	DAU	YEAR	GMU	COUNT_TYPE	MEMO_GMU	SUB_AREA	YEARLING_M	TWOYR_M	ADULT_M	FEMALES	YOUNG	UNCLASS	GROUP
2	D-98	2004	888	POST	888	Area 1	0	0	0	7	5	0	1
3	D-98	2004	888	POST	888	Area 1	2	4	6	8	10	12	2
4	D-98	2004	888	POST	888	Area 1	2	2	0	2	0	0	3
5	D-98	2004	888	POST	888	Area 1	0	0	0	5	0	0	4
6	D-98	2004	888	POST	888	Area 2	2	4	6	8	10	12	1
7	D-98	2004	888	POST	888	Area 3	0	0	1	5	4	0	1
8	D-98	2004	888	POST	888	Area 4	1	0	0	1	2	0	1
9	D-98	2004	888	POST	888	Area 21	1	2	3	4	5	6	1
10	D-98	2004	888	POST	888	Area 21	1	2	3	4	5	6	2
11	D-98	2004	888	POST	888	Area 21	1	2	3	4	5	6	3
12	D-98	2004	888	POST	888	Area 22	1	2	3	4	5	6	1
13	D-98	2004	888	POST	888	Area 22	1	2	3	4	5	6	2
14	D-98	2004	888	POST	888	Area 22	1	2	3	4	5	6	3
15	D-98	2004	889	POST	888	Area 1	0	0	0	7	5	0	1
16	D-98	2004	889	POST	888	Area 1	2	4	6	8	10	12	2
17	D-98	2004	889	POST	888	Area 1	2	2	0	2	0	0	3
18	D-98	2004	889	POST	888	Area 1	0	0	0	5	0	0	4
19	D-98	2004	889	POST	888	Area 2	2	4	6	8	10	12	1
20	D-98	2004	889	POST	888	Area 3	0	0	1	5	4	0	1
21	D-98	2004	889	POST	888	Area 4	1	0	0	1	2	0	1
22	D-98	2004	889	POST	888	Area 21	1	2	3	4	5	6	1
23	D-98	2004	889	POST	888	Area 21	1	2	3	4	5	6	2
24	D-98	2004	889	POST	888	Area 21	1	2	3	4	5	6	3
25	D-98	2004	889	POST	888	Area 22	1	2	3	4	5	6	1
26	D-98	2004	889	POST	888	Area 22	1	2	3	4	5	6	2
27	D-98	2004	889	POST	888	Area 22	1	2	3	4	5	6	3

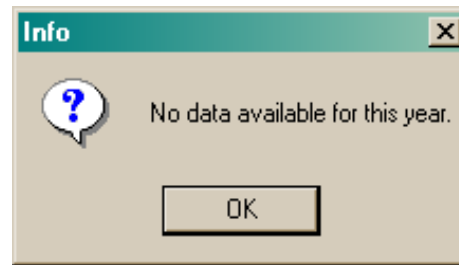
After the spreadsheet has been processed, a memo will be created and presented to you to be saved in the AGSX_MEM database, similar to the “Generate Memo and Close” button for the regular data entry mode.

If you discover a mistake in your spreadsheet after the data have been read into DEAMAN, you will need to delete all of the observations from the AGE_SEX database and the AGSX_MEM database. You can do this by opening these databases with a filter to only show the appropriate records, and then clicking on the garbage can icon to delete the highlighted record.

Once all the data for a DAU has been entered (which might consist of more than 1 memo because of different GMUs, as described above), you can examine both the data and the memo created. The following memo choices allow you to examine your entries.



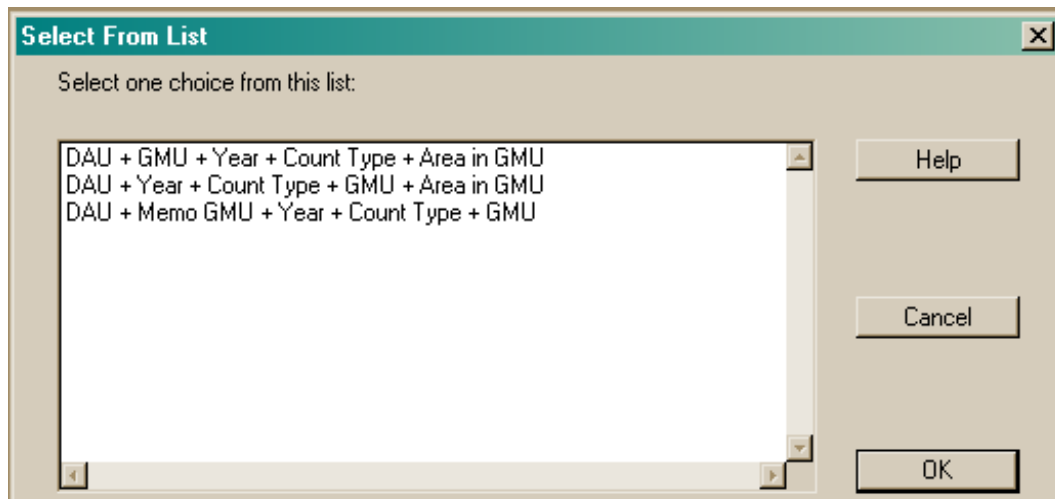
The choice “Examine Age and Sex Ratio Memos” leads to a dialog box to select the DAU, GMU, and Year of the memo you want to examine. Often, after you have selected your choices, you get the message:



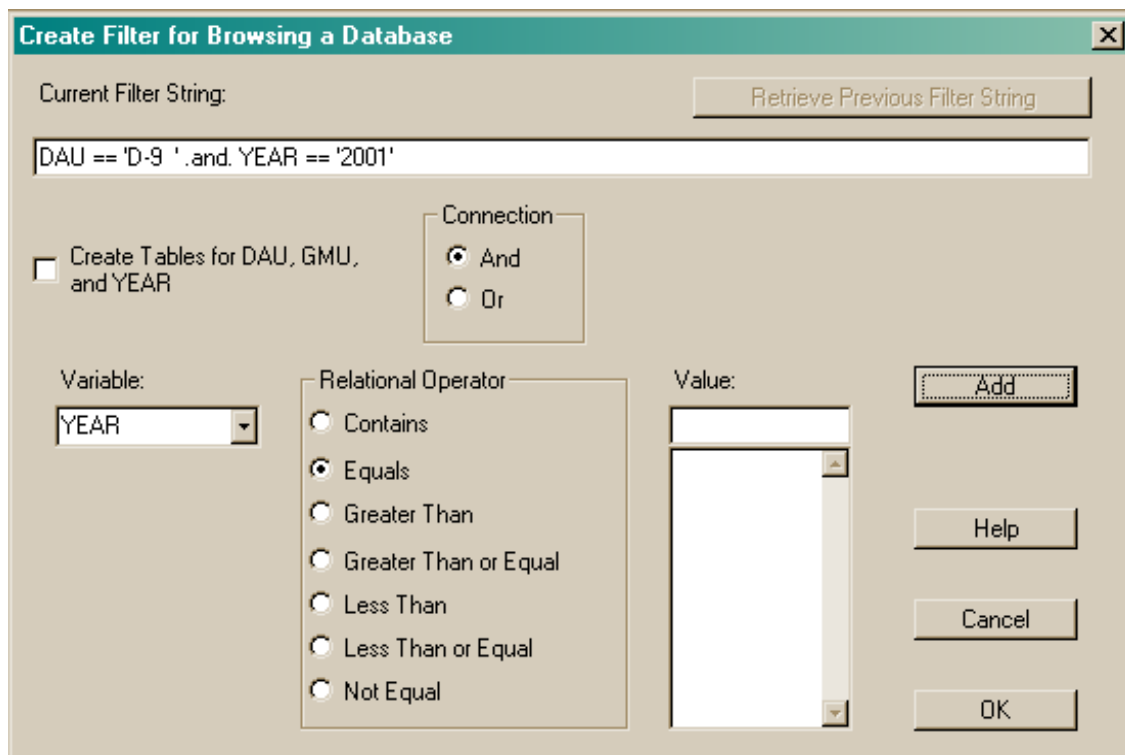
This message means that no memo exists for the specific GMU you requested. If you know that you have entered data for this GMU, you likely stored it under a different GMU memo. Therefore, go back to the previous menu and try a different GMU number.

Tip: To discover what GMUs have been used to store data in the AGSX_MEMO.DBF file, use the “Browse or Edit Age and Sex Memos” choice to browse the file and see what memo records are available.

The highlighted choice “Browse or Edit Age and Sex Ratio Counts” allows you to check the age and sex database (AGE_SEX.DBF) to see what data are available. Selecting this menu choice leads to the following dialog box. You are being asked to select the order of the records in the AGE_SEX.DBF file that you want to view them in. The first choice of “DAU+GMU+Year+Count Type+Area in GMU” would have all the data for a GMU together, whereas the second choice would put all the data for one year in the same block, with GMUs reported within year. You should explore these different orderings to become familiar with them. Each of these orderings represents a different index file for the AGE_SEX.DBF database.




Selecting the first choice and clicking on the “OK” button then results in the “Filter” screen. This screen is very useful in filtering a database so that you only see a portion of the data. So, suppose that you only want to see the D-9 age and sex ratio data for the year 2001. To do this, you select the DAU variable from the list of variables in the left center box, Tab over to specify you want an equals operator, and then Tab over to the Value box, and enter “D-9” into the Value box. Note that you don’t want any blanks preceding the “D”, and no intervening spaces. Then, Tab over to the Add button and click it. The expression you just created will appear in the “Current Filter String” at the top of the window.

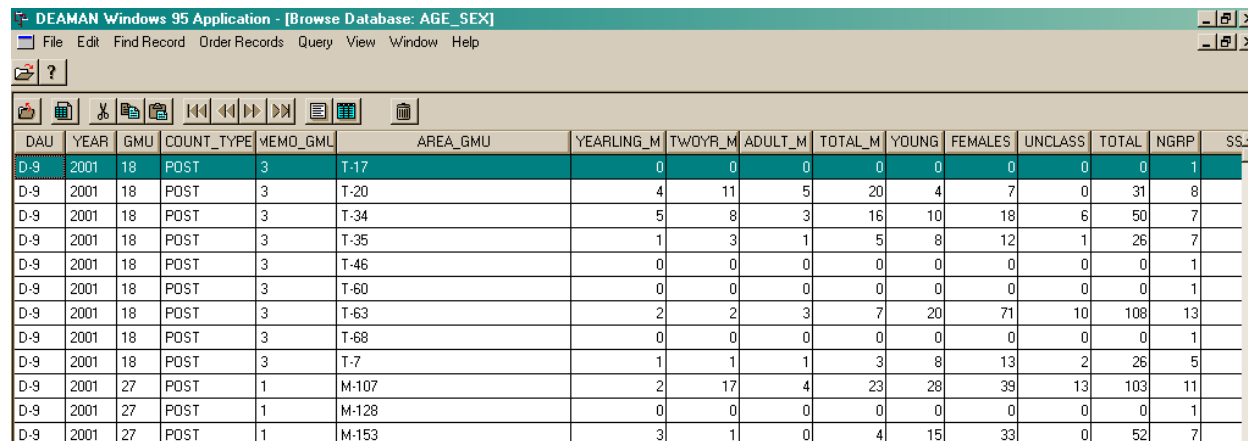


In the example above, the Year has also been specified to equal 2001, and added to the current filter string. Note that the connection between the DAU clause and the Year clause can be either “And” or “Or”, which you specify with the Connection radio buttons. In this case, you want to only see the data for D-9 in 2001, so you want an “And” connection.

Also useful is that you can edit the expression that is being created in the current string. If you make a mistake, just change the value in the string. Be careful to not insert extraneous blanks. As an example “DAU == ‘D-9’ ” is not the same as “DAU == ‘ D-9’ ” because of the blank in front of D-9 in the second expression. The second expression will result in NO data being found because of the extra blank.

When you have created the filter expression you want, select the “OK” button to proceed. The following browser window will appear. I have taken just the top part of the window to save space, plus I made the window full screen before I copied it by clicking on the box buttons at the upper right of the main DEAMAN window and the browser window.


 **Tip:** The filter capability can be used to brows any DEAMAN database. Just select the File | Filter Open menu choices, select the desired database, index ordering, and specify your filter.



DAU	YEAR	GMU	COUNT_TYPE	MEMO_GMU	AREA_GMU	YEARLING_M	TWOYR_M	ADULT_M	TOTAL_M	YOUNG	FEMALES	UNCLASS	TOTAL	NGRP	SS
D-9	2001	18	POST	3	T-17	0	0	0	0	0	0	0	0	0	1
D-9	2001	18	POST	3	T-20	4	11	5	20	4	7	0	31	8	
D-9	2001	18	POST	3	T-34	5	8	3	16	10	18	6	50	7	
D-9	2001	18	POST	3	T-35	1	3	1	5	8	12	1	26	7	
D-9	2001	18	POST	3	T-46	0	0	0	0	0	0	0	0	0	1
D-9	2001	18	POST	3	T-60	0	0	0	0	0	0	0	0	0	1
D-9	2001	18	POST	3	T-63	2	2	3	7	20	71	10	108	13	
D-9	2001	18	POST	3	T-68	0	0	0	0	0	0	0	0	0	1
D-9	2001	18	POST	3	T-7	1	1	1	3	8	13	2	26	5	
D-9	2001	27	POST	1	M-107	2	17	4	23	28	39	13	103	11	
D-9	2001	27	POST	1	M-128	0	0	0	0	0	0	0	0	0	1
D-9	2001	27	POST	1	M-153	3	1	0	4	15	33	0	52	7	

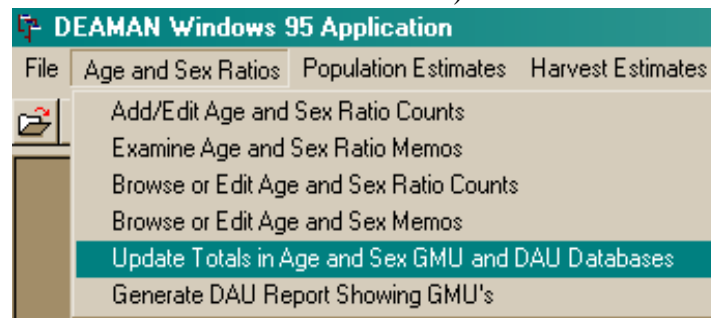
You see some of the same data listed here as in the memo and list data examples shown above.

Note that you should NOT edit these data at this point. This is because there are a number of additional variables off the right side of the screen that hold various summary statistics, i.e., sums of squares and cross products needed to compute the appropriate

 **Tip:** If you discover an error in the AGE_SEX.DBF file, you must delete the incorrect record from the AGE_SEX.DBF file (note the garbage can button on the browser window which allows you to delete a record), and go back into the age and sex ratio data entry and redo the entry for this quadrat or sub-area.

variances of the age and sex ratio estimates (see Bowden et al. 1984 for more details if you are so inclined, included here as Appendix I).

Once you have entered all the data for a DAU, you'll want to update the totals in the GMU and DAU age and sex ratio databases, AGSX_GMU.DBF and AGSX_DAU.DBF, respectively. To do this, select the menu choices shown in the following display. A set of windows showing the progress of the update will be displayed, allowing you to see the development. You may also encounter some warnings about errors, where GMU and DAU links are incorrect in the files. For the moment, just remember what these errors are, and you can fix them later (described in the Maintenance section below).



Once the GMU and DAU databases are updated, you can generate a report for the entire DAU, with this menu choice shown just below the highlighted choice above. After you specify the DAU and year (and select a GMU in the memo file so that you want to summarize, this menu choice results in the following report, useful for summarizing the age and sex results for a specific year. Note in this example that all the quadrat data were entered under GMU 18 as 1 memo, so the data of the counts for GMUs 27, 28, 37, and 181 was not found.

DEAMAN Windows 95 Application - [Untitled]

File Edit Window Help

Species: Deer
DAU: D-9
Year: 2001
Type of Count
Pre Post XX

DAU Age and Sex Ratio Summary

Date of Counts	GMU	Yrlg. Males		2-Yr. Males		Adult Males		Total Males		Juveniles	
		Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE
Dec 27 and 29, 2001	18	10.7	3.5	20.7	8.8	10.7	4.2	42.1	38.3	41.3	5.2
Not Found	27	6.4	3.0	25.6	6.4	9.0	3.5	41.0	8.6	59.0	11.0
Not Found	28	10.8	3.6	12.8	3.0	6.1	2.4	29.7	40.9	43.2	6.4
Not Found	37	8.5	2.1	9.8	2.2	7.8	2.4	26.1	17.4	42.4	3.3
Not Found	181	15.6	4.8	14.3	4.6	10.4	3.9	40.3	8.6	76.6	13.3
DAU Total		10.1	1.7	15.6	3.9	8.6	1.7	34.3	5.9	50.9	4.1

Occasionally, the DAU Total in the above table appears to be way out of line with the various GMU values listed. This is caused by different sample sizes for the GMUs in ad hoc surveys, and by both sample size and area for the quadrat-based surveys.

Probably the most common error in age and sex ratio data is that 2 records get put into the AGE_SEX.DBF file that have the same quadrat or sub-area designation. These records may or may not be perfect duplicates, i.e., the counts may or may not be the same. A useful way to detect these records is to browse the AGE_SEX.DBF file after data entry to be sure that you did not accidentally enter 2 records with the same identifying information. Although duplicate records should be obvious, I often see them in the AGE_SEX.DBF files that others send me. These duplicate records cause the sample size of the age and sex ratio estimates to be doubled, and thus are causing errors of which users are not aware.

Tip: To see how your current age and sex ratios align with past data, you can graph the history of the estimates. Select the "DAU Summaries" menu choice from the main menu. Details of this procedure are described in the "Graphical Summaries of a Single DAU" section below.

If multiple copies of the same record, or an incorrect record is discovered for which a correct record has been entered, the extra records should be deleted. However, you will then

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have to re-do the update of the AGSX_GMU.DBF and AGSX_DAU.DBF files, as described above.

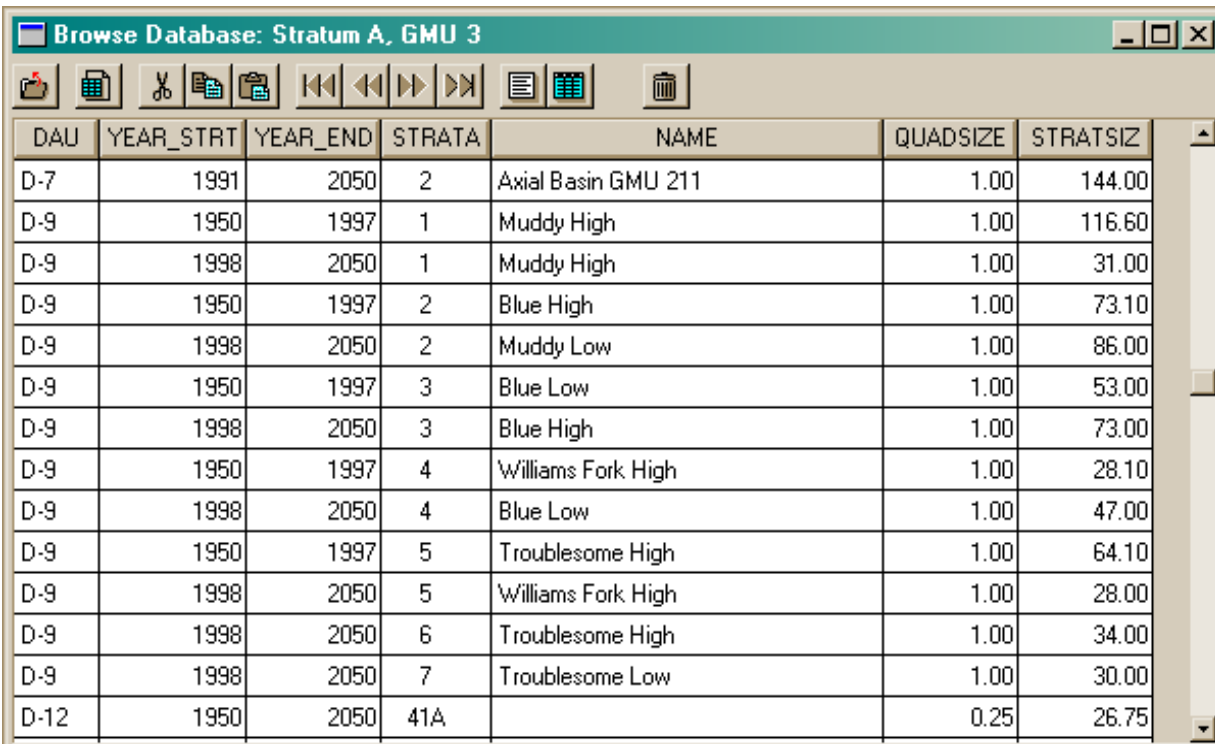
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Population estimation data

Two different population estimation schemes are built into DEAMAN: quadrat surveys and line transect surveys. Because quadrat surveys are the most used approach in Colorado, and are the method used in the intensively monitored DAUs, I'll start with them.

Quadrat counts

As with quadrat counts for age and sex ratio data, you must specify the information on stratification BEFORE you attempt to enter population counts on the quadrats to be used for population information. This process is similar to the age and sex ratios quadrat stratification, except that the quadrat stratification file is named QUADSTRT.DBF. You select the File | Open menu choices from the main DEAMAN menu, and open up the QUADSTRT.DBF file, as shown below.




DAU	YEAR_STRT	YEAR_END	STRATA	NAME	QUADSIZE	STRATSIZ
D-7	1991	2050	2	Axial Basin GMU 211	1.00	144.00
D-9	1950	1997	1	Muddy High	1.00	116.60
D-9	1998	2050	1	Muddy High	1.00	31.00
D-9	1950	1997	2	Blue High	1.00	73.10
D-9	1998	2050	2	Muddy Low	1.00	86.00
D-9	1950	1997	3	Blue Low	1.00	53.00
D-9	1998	2050	3	Blue High	1.00	73.00
D-9	1950	1997	4	Williams Fork High	1.00	28.10
D-9	1998	2050	4	Blue Low	1.00	47.00
D-9	1950	1997	5	Troublesome High	1.00	64.10
D-9	1998	2050	5	Williams Fork High	1.00	28.00
D-9	1998	2050	6	Troublesome High	1.00	34.00
D-9	1998	2050	7	Troublesome Low	1.00	30.00
D-12	1950	2050	41A		0.25	26.75

I have manipulated the display so that the last record for D-7 is at the top, and the first record for D-12 is at the bottom. There are 2 complete sets of stratifications shown for D-9. The first stratification pertained to the time period 1950 to 1997. In 1998, the DAU was re-stratified to provide more precise estimates of the population size with less flying based on the past surveys to design this improved stratification.

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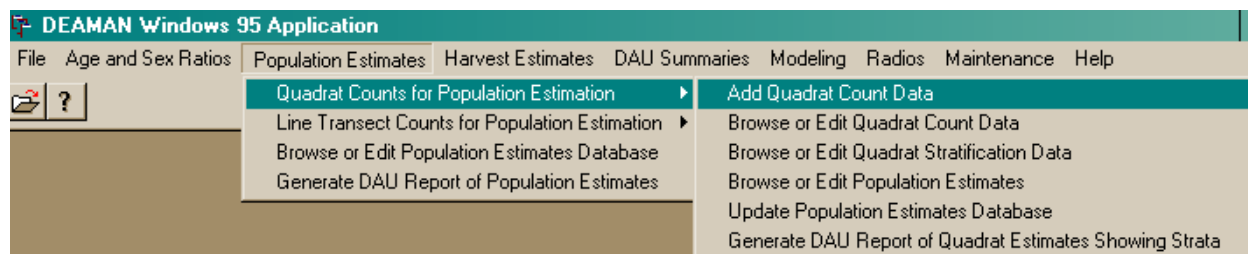
Besides the DAU, the starting and ending year, the strata id, and the strata name, the other critical pieces of information are the size of quadrats in the strata, and the size of the strata, both in square miles. The critical assumption to valid population estimates from quadrat counts is that no animals are missed, but that none are counted more than once either. This assumption makes counting quadrats a tricky process. Hence, quadrat size is an important variable that affects the bias and precision of the method. For open sage brush stratum, a quadrat size of 1 mi² may be appropriate. In contrast, for a mostly pinyon-juniper stratum, 1/4 mi² quadrats would be more appropriate. You can have different sized quadrats in different strata, but all the quadrats within a strata must be the same size. Typically, quadrats of sizes 1/4 mi² and 1mi² are used in Colorado.

 Tip: Be sure to have the correct stratification system in place in the QUADSTRT.DBF file before entering population count data, or you'll have to re-enter the data with the correct stratification system later.

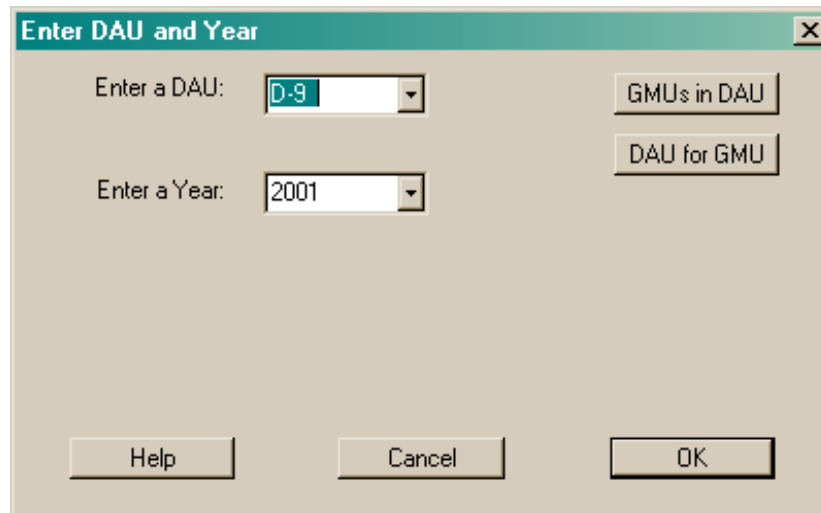
To add a new stratification to the QUADSTRT.DBF file, click the Edit | Insert Record menu choices, and insert a record. Repeat the process for additional records. To change the contents of an existing record, double click the field, and enter the new values. You can delete a record with the garbage can icon, or the Edit | Delete Record menu choice.

Note that you do not want to delete old stratification systems that have data associated with them already entered into the database. This information should be preserved. Rather, change the YEAR_END variable on the old system to reflect when it was last used, and set the YEAR_STRT variable on the new stratification system to show when it started.

To select the menu choices to enter quadrat counts for population estimation, follow the menu choices displayed below.



You will be asked to select the DAU and year you want to enter data for, shown below.



As with age and sex ratio data, you have 2 buttons to help you remember which GMUs belong in what DAU, and vice versa. They operate exactly the same as described above for age and sex ratio data entry. There is also a “Help” button to assist you with data entry.

Note that no GMU is requested. Population estimates pertain to the DAU, and the sampling frame should reflect the entire DAU area, not just a specific GMU.

Once you enter values and select “OK”, the following dialog window appears. You are asked to enter the strata for the counts, the quadrat identification, and the number of animals counted. Then, you can put these values into the table on the lower left side of the screen by clicking the “Add Count to Data Table” button. You continue this process for each of the quadrats in each of the strata, clicking the “Add” button (or hitting the “Enter” key). Once you are done entering the quadrat counts for all the strata, click the “Generate Population Estimate” button to see your population estimate.

⊗Tirade: DO NOT survey just a portion of a DAU as part of a population estimate. The result is that the data entered into DEAMAN make the population estimate for the DAU appear much lower than it should be. Models require DAU-level population estimates, and estimates applicable to only a portion of the DAU lead to grievous mistakes in interpretation.

DEAMAN Windows 95 Application - [Untitled]

File Edit Window Help

1998 Mule Deer Population Estimates for DAU
D-9, Middle Park

Strata	Sq. Mi.	No. Quadrats		Anim. Cntd.	Anim./Quadrat		Anim./Sq. Mi.	Population	
		Poten.	Sample		Mean	StdErr.		Total	95% CI
1	31.00	31	11	582	52.91	12.335	52.91	1641	750
2	86.00	86	4	13	3.25	3.174	3.25	280	535
3	73.00	73	18	730	40.56	7.641	40.56	2961	1094
4	47.00	47	6	144	24.00	9.843	24.00	1128	907
5	28.00	28	6	378	63.00	26.409	63.00	1764	1450
6	34.00	34	6	494	82.33	24.589	82.33	2800	1639
7	30.00	30	5	74	14.80	5.396	14.80	444	318
DAU	329.00		56	2415			33.48	11016	2785

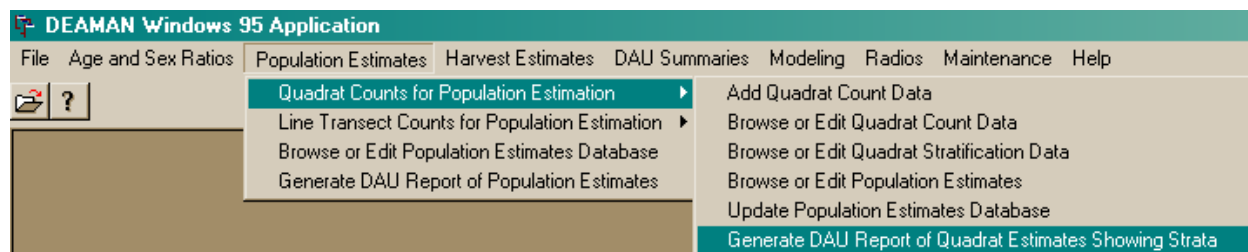
95% Confidence Interval on DAU Population: 8232 to 13800
 95% Confidence Interval as percent of estimate: 25.27%
 Percent of DAU sampled: 17.02%

Question

? Append these results to the Population Estimates Database?

Yes No

Other options are available for the display of quadrat count population data, shown in the following menus.



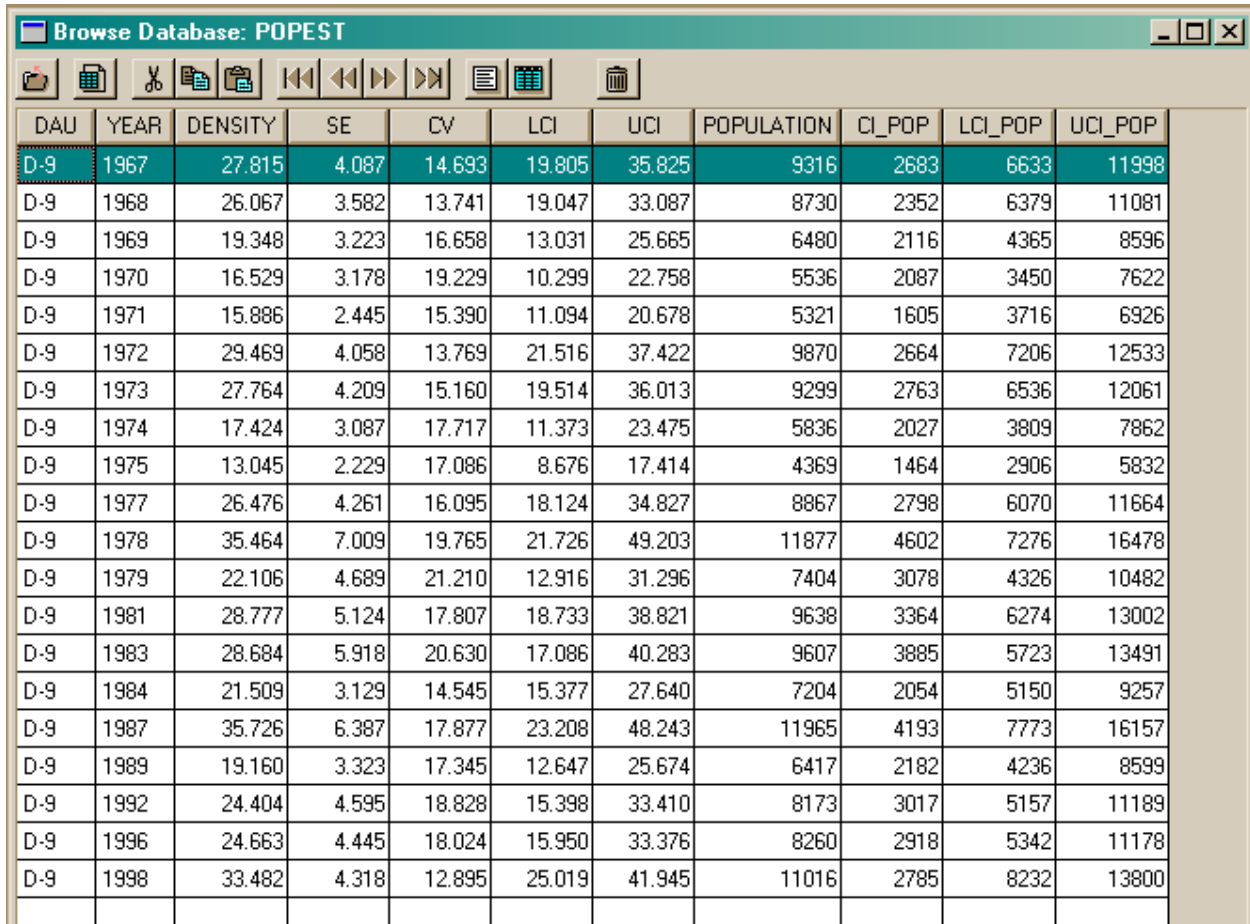
Options are available to browse or edit the quadrat count data you have entered, browse or edit the stratification data, browse or edit (hopefully not!) the population estimates, update the population estimates after you've changed the quadrat count data, and to generate a report like the one shown above of the population estimates by strata.

As an example, if you select the "Browse or Edit Quadrat Count Data", you'll be asked to specify a filter so that only a portion of this large file is displayed. If you don't want to filter the database, just click "OK" immediately, and the entire database will be available in the browser window. In the example to the right, I have selected just the D-9 data for 1998, with only a portion of the data shown. The high-lighted record is the count for quadrat 17 in strata 2, where no deer were counted. To get this screen to appear this way, I drug the right side of the window to the right by clicking on the window boundary and holding down the left mouse button while dragging to the right. I did the same for the bottom to get window vertically stretched to view the amount of data shown.

If you were to notice a mistake at this point, the correction is much easier to make than with age and sex ratios, because the actual raw counts of animals per quadrat are stored in the QUADRATS.DBF file. Just change the count in error to the correct value by clicking on the field, and re-entering the observation. When you've got everything corrected, select the "Update Population


DAU	YEAR	STRATA	QUADRAT	COUNT
D-9	1998	1	7	182
D-9	1998	1	8	35
D-9	1998	1	9	24
D-9	1998	1	10	72
D-9	1998	1	12	60
D-9	1998	1	13	32
D-9	1998	1	15	94
D-9	1998	1	33	0
D-9	1998	1	34	46
D-9	1998	1	35	5
D-9	1998	1	36	32
D-9	1998	2	17	0
D-9	1998	2	19	13
D-9	1998	2	21	0
D-9	1998	2	32	0
D-9	1998	3	1	37
D-9	1998	3	4	1
D-9	1998	3	7	70
D-9	1998	3	8	88
D-9	1998	3	9	53

Estimates” menu choice shown above, and re-generate the estimates in the population database. An example of what this database contains is shown below, where I have opened it with a filter to just show the D-9 data across years. Note that you can access the POPEST.DBF database from either the menus shown in the above display, or from the File | Open or File | Filter Open menu choices. As described above, I have used the mouse to adjust the size of this display.



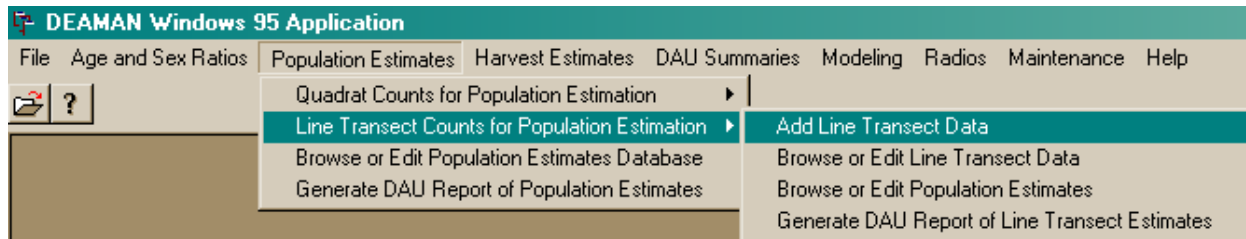
DAU	YEAR	DENSITY	SE	CV	LCI	UCI	POPULATION	CI_POP	LCI_POP	UCI_POP
D-9	1967	27.815	4.087	14.693	19.805	35.825	9316	2683	6633	11998
D-9	1968	26.067	3.582	13.741	19.047	33.087	8730	2352	6379	11081
D-9	1969	19.348	3.223	16.658	13.031	25.665	6480	2116	4365	8596
D-9	1970	16.529	3.178	19.229	10.299	22.758	5536	2087	3450	7622
D-9	1971	15.886	2.445	15.390	11.094	20.678	5321	1605	3716	6926
D-9	1972	29.469	4.058	13.769	21.516	37.422	9870	2664	7206	12533
D-9	1973	27.764	4.209	15.160	19.514	36.013	9299	2763	6536	12061
D-9	1974	17.424	3.087	17.717	11.373	23.475	5836	2027	3809	7862
D-9	1975	13.045	2.229	17.086	8.676	17.414	4369	1464	2906	5832
D-9	1977	26.476	4.261	16.095	18.124	34.827	8867	2798	6070	11664
D-9	1978	35.464	7.009	19.765	21.726	49.203	11877	4602	7276	16478
D-9	1979	22.106	4.689	21.210	12.916	31.296	7404	3078	4326	10482
D-9	1981	28.777	5.124	17.807	18.733	38.821	9638	3364	6274	13002
D-9	1983	28.684	5.918	20.630	17.086	40.283	9607	3885	5723	13491
D-9	1984	21.509	3.129	14.545	15.377	27.640	7204	2054	5150	9257
D-9	1987	35.726	6.387	17.877	23.208	48.243	11965	4193	7773	16157
D-9	1989	19.160	3.323	17.345	12.647	25.674	6417	2182	4236	8599
D-9	1992	24.404	4.595	18.828	15.398	33.410	8173	3017	5157	11189
D-9	1996	24.663	4.445	18.024	15.950	33.376	8260	2918	5342	11178
D-9	1998	33.482	4.318	12.895	25.019	41.945	11016	2785	8232	13800

You see that both density of deer on the winter range as well as the population size are shown. The density estimate includes a standard error, coefficient of variation, and lower and upper 95% confidence intervals. The population only has the confidence interval width and lower and upper 95% bounds listed. The size of the strata specified in the QUADSTRT.DBF file is used to compute the density of animals.

 Tip: To see how your population estimates align with past data, you can graph the history of the estimates. Select the “DAU Summaries” menu choice from the main menu. Details of this procedure are described in the “Graphical Summaries of a Single DAU” section below.

Line transect counts

Line transect counts are added to DEAMAN with the menu choices displayed below.



Selecting this set of menu choices results in the usual screen requesting a DAU and a year to which the population estimate will pertain. Once these have been chosen, the following window appears.

The screenshot shows a window titled 'DataWindow Caption' with the subtitle 'Line Transect Data Entry for DAU D-99 in 2001'. The window contains the following elements:

Current Group

Line: Group Size:

Line Length (m): Distance (m):

Groups Entered:

Line:	Line Length:	Group Size:	Distance:

Data entry is similar to for line transects as to other data entry procedures in DEAMAN. For each group of animals observed, you enter the line, the group size or number of animals in the

group, the length of the line in meters, and the distance to the group of animals from the line in meters. Once, this information is entered, you can add the data to the data table by clicking the "Add Group to Table" button. If you make a mistake, highlight the incorrect record in the data table, and click the "Delete Highlighted Group" push button to remove the data from the data table.

A tricky little problem occurs when you have flown a line and not observed any groups of animals. You still have to enter the line identification and length to obtain valid line transect estimates, because the line was flown even though no animals were counted (like a quadrat with zero animals for quadrat sampling). Specify a group size of zero, leaving the distance to the group blank or zero, so that a record is put into the LINETRAN.DBF file showing the length of the line flown, and that no animals were observed.

Once you have entered all the data for a survey, click the "Generate Population Estimate" push button at the bottom of the screen to generate the population estimate. The next window is requesting input parameters for the Distance program. To run Program Distance, you must specify an input file for the program (with a default provided), a set of cut points that are used to partition the observed distances into categories (with a reasonable default provided), a truncation width beyond which observations are discarded (with the default based on the White et al.1989 results), a key function, and an adjustment function for this key function. All of these values are given defaults, but knowledgeable users are allowed to change these defaults to attempt to obtain better line transect estimates.

Program Distance Parameters

Root name of file for input to Program Distance:

D:\Deaman32\Reports\E-81_LT.INP

Default cutpoints are:

0, 15, 25, 35, 45, 55, 65, 75, 85, 95

Truncation Width: 155 View Histogram

HNormal

- ☐ Hazard
- ☐ Uniform
- ☒ HNormal
- ☐ NExpon

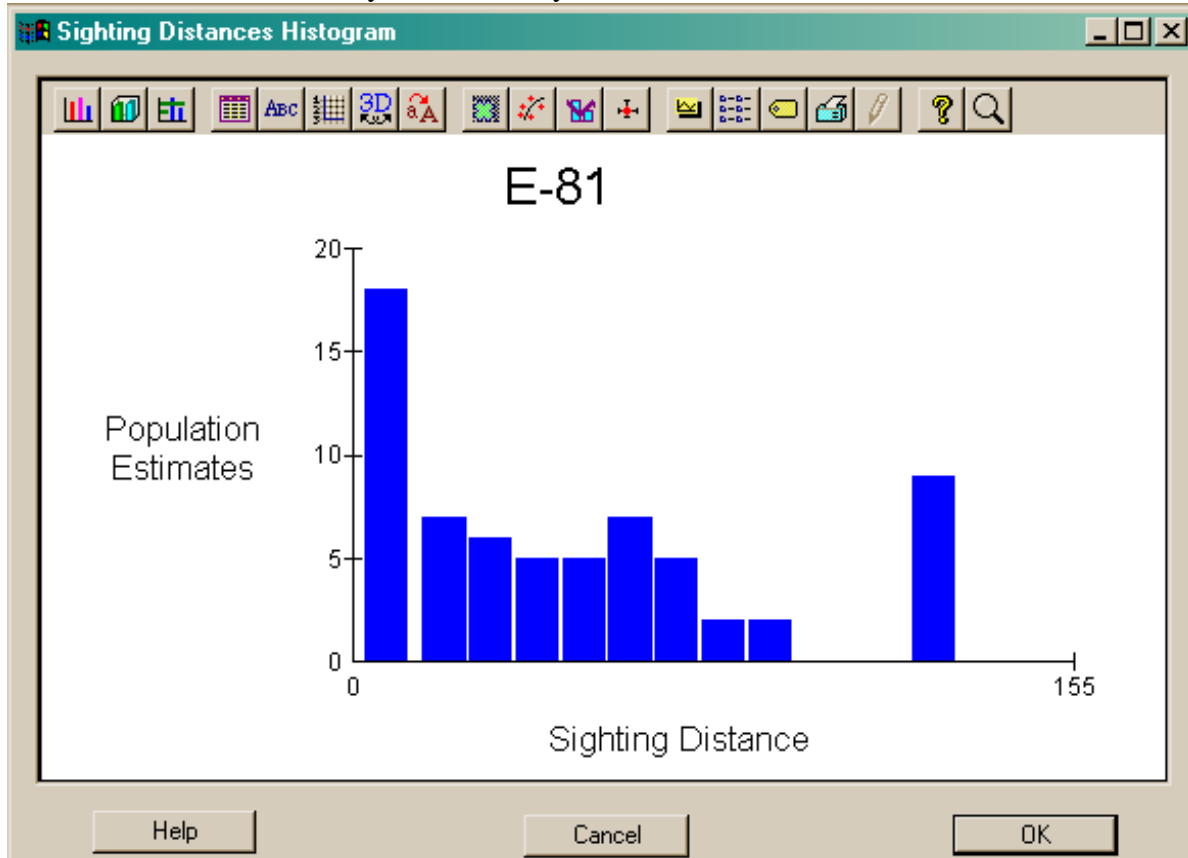
Cosine

- ☒ Cosine
- ☐ Polynomial
- ☐ Hermite

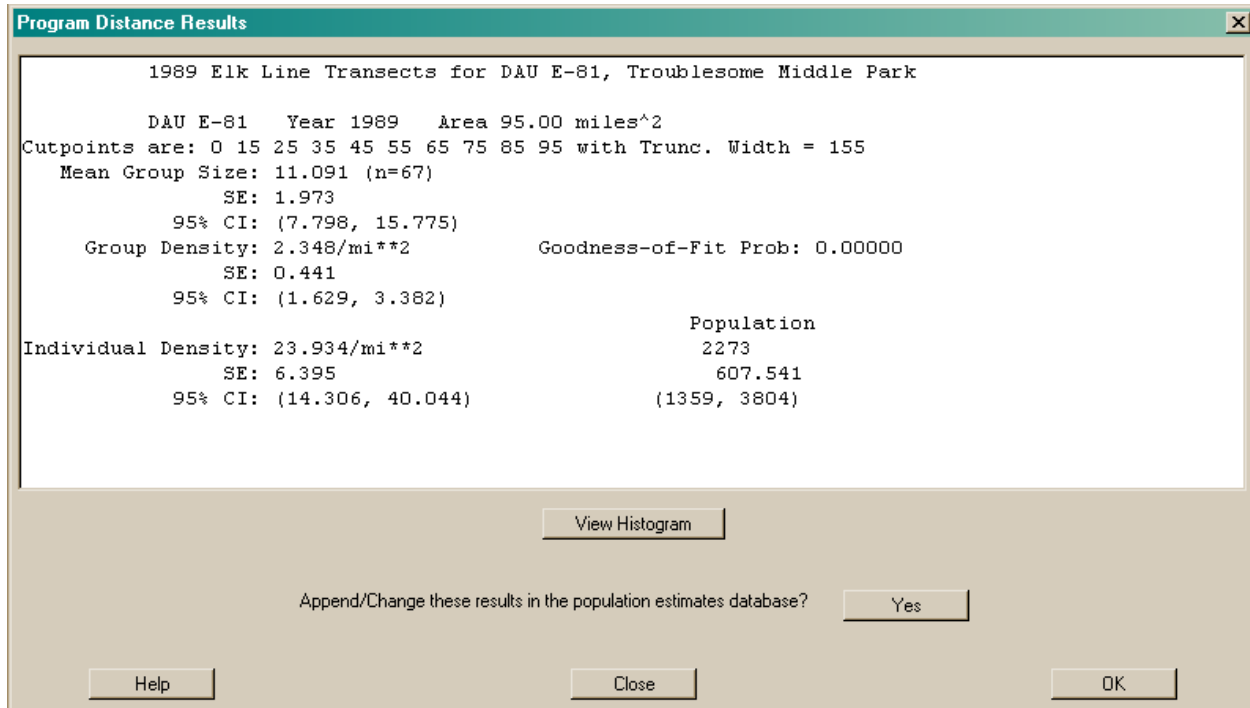
Help Cancel OK

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In addition, you have the option of viewing the histogram of your distance data for the cutpoints you have entered by clicking the "View Histogram" push button. Results are shown below for the E-81 1989 data collected by David Freddy in Middle Park.

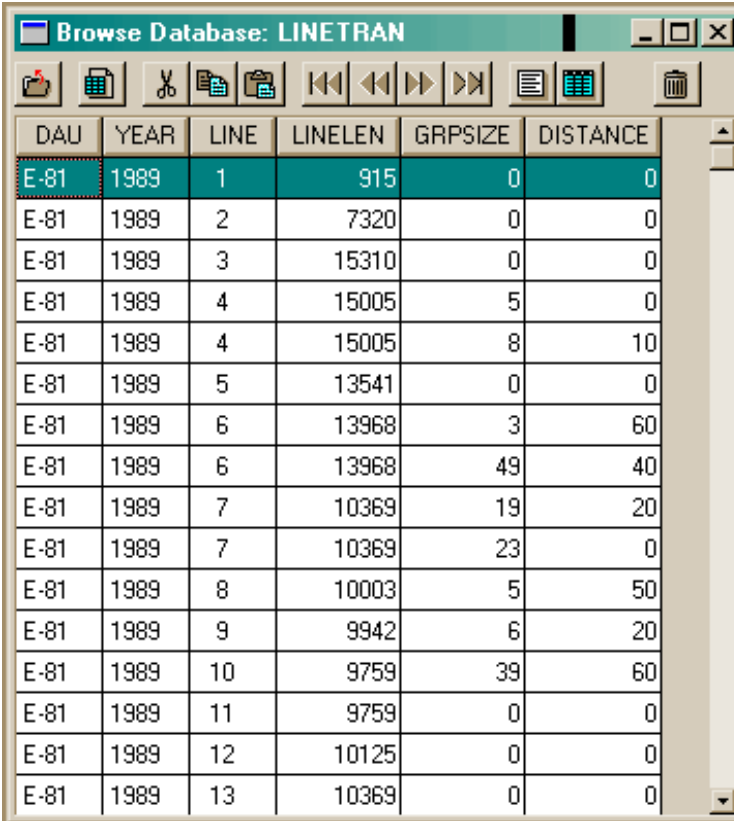


After viewing the histogram, you can click "OK" to return to the previous screen, and there click "OK" to proceed with the population estimation. Program Distance is run, and the results are summarized in a window as displayed below. The population density and population estimate, plus associated standard errors and 95% confidence intervals are displayed on the screen, plus other pertinent information appropriate to interpreting the estimates.



The “View Histogram” button allows you to view the fit of the model to the observer sighting distances. However, the most important question is whether to append these estimates to the POPEST.DBF database. Doing so will overwrite any other estimates for E-81 in 1989, so this “Yes” button should not be clicked until you are sure that you want to replace any existing estimates made at some other time. Normally, you will only append the estimates when you first enter the line transect data.

Line transect data can be edited and changed at any time by selecting the “Browse or Edit Line Transect Data” menu option shown above, or by selecting the File | Open or File | Filter Open menu choices. An example for the E-81 1989 data are shown below. Note that no animals were sighted for the first 3 lines, but that 2 groups were seen for line 4, the first group of 5 at a distance of zero meters off the line, and the second group of 8 at a distance of 10 meters off the line.



DAU	YEAR	LINE	LINELEN	GRPSIZE	DISTANCE
E-81	1989	1	915	0	0
E-81	1989	2	7320	0	0
E-81	1989	3	15310	0	0
E-81	1989	4	15005	5	0
E-81	1989	4	15005	8	10
E-81	1989	5	13541	0	0
E-81	1989	6	13968	3	60
E-81	1989	6	13968	49	40
E-81	1989	7	10369	19	20
E-81	1989	7	10369	23	0
E-81	1989	8	10003	5	50
E-81	1989	9	9942	6	20
E-81	1989	10	9759	39	60
E-81	1989	11	9759	0	0
E-81	1989	12	10125	0	0
E-81	1989	13	10369	0	0

When the data in the LINETRAN.DBF file are be changed in the file browser window, the population estimates should be re-generated through Program Distance with the “Generate DAU Report of Line Transect Estimates” menu choice, and the new estimates placed in the POPEST.DBF database.

Survival data from radio collared animals

Data can be entered directly into the DEAMAN RADIOS.DBF file, or imported directly from the RADIOS program. To enter data on the survival of a radio-collared animal, select the menu choice Radios on the DEAMAN main menu to open the RADIOS.DBF file in the file browser window. You will see a window like the following.

The screenshot shows a window titled "Radios Database" with a toolbar at the top containing icons for file operations and navigation. The main area contains numerous input fields organized as follows:

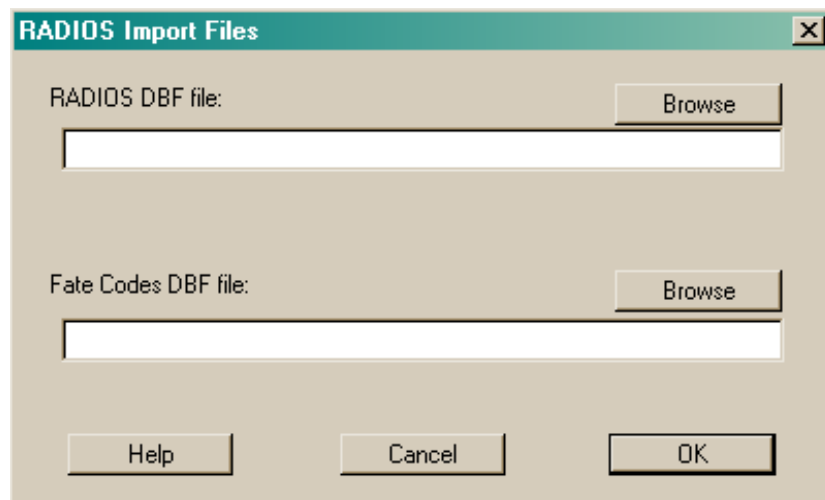
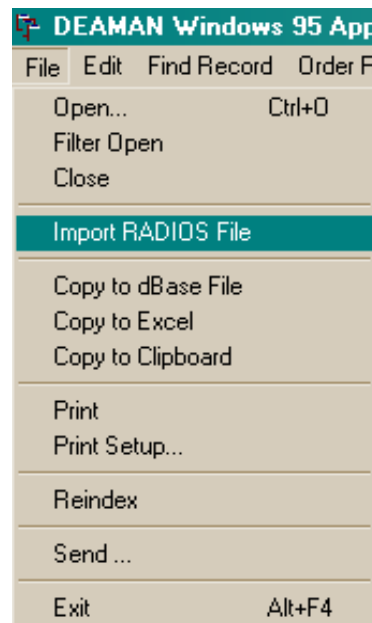
- Top Section:**
 - DAU: Year: GMU:
 - Animal ID: Capture Date: Zone: UTM X: UTM Y:
 - Trapsite: Pasture:
 - Recorder:
- Sex and Age Section:**
 - Sex: Age: Ear tag Left: Ear tag Right:
- Frequency and Collar Section:**
 - Frequency: Radiotype: Listen for Freq: CDOW Collar ID:
- Weight and Body Measurements Section:**
 - Wgt Gross: Bodylen:
 - Wgt Tare: Hindfoot:
 - Wgt Deer:
- UTM and Date Section:**
 - Date Last Heard Alive: UTM X:
 - Date First Heard Dead: UTM Y:
 - Date Radio Recovered: Zone:
- Points and Burr Section:**
 - Burr L: Burr R:
 - Main L: Main R:
 - Points L: Points R:
 - Brow L: Brow R:
- Time and Fate Section:**
 - Time Dead: Fate: Standardized Fate:
- Comments and Metadata Section:**
 - Undetermined mortality: Other Cause of Death:
 - Comments:
 - Date Mod: Record Number 1 of 3038

At the bottom left, there is a label "DAU Name" followed by a small icon.

By using the Edit | Insert Record or Edit | Insert Copy of Current Record, you can add a record to the RADIOS.DBF file to hold the information on the new animal to be added. By using a copy of a current record, a template is provided so that fewer of the fields have to be modified for the new record.

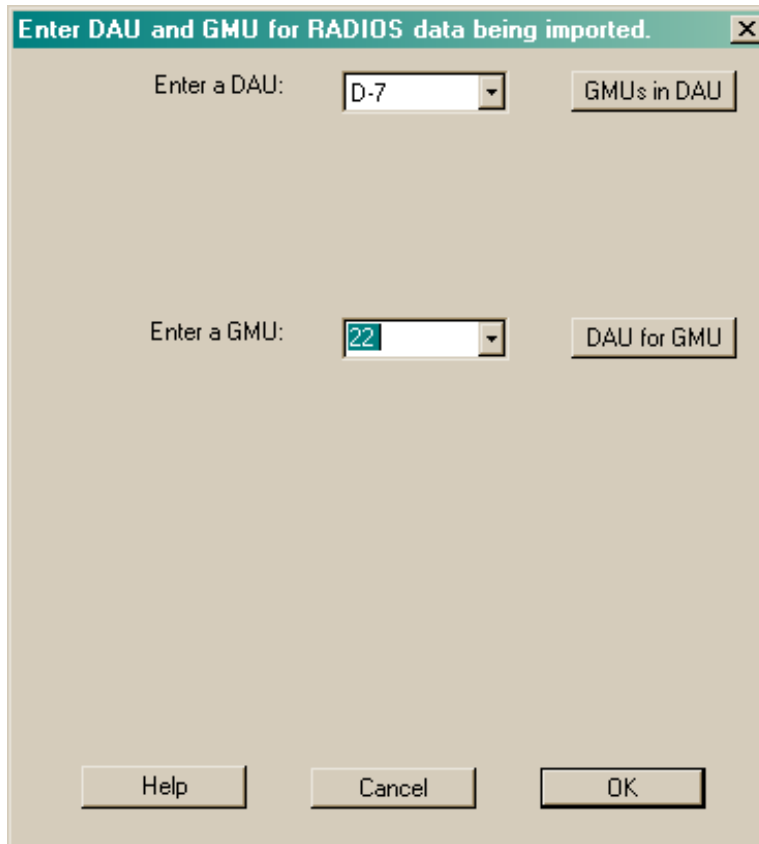
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However, the most efficient method of getting data into the DEAMAN Radios database is through the File | Import RADIOS File command shown to the right. When you select this menu choice, you will be asked to identify the file from the RADIOS Program that you want to import. Also requested is the file used by the RADIOS Program to label the fate codes used in the RADIOS file you have selected. These fate codes are needed to be able to assign new codes consistent with the fate codes in DEAMAN to the imported data. This process is required because there are no standardized fate codes being used across the state with the RADIOS Program, with each user assigning different codes, sometimes even different codes for different species. The result is that I have had to develop a minimum set of codes for use in DEAMAN, and the user has to make a translation of their codes to the set in DEAMAN. The window to the left shows the file selection window, with the request for the 2 files to import. Each file has a "Browse" button that you can use to open a typical file selection dialog window to locate the file on your hard drive. Be sure that the RADIOS and the Fate Code file are matched, i.e., don't accidentally select a RADIOS file from one subdirectory and a FCODE file from a different subdirectory.



Once these files are selected, you will be asked to specify the DAU and GMU where these radioed animals were tracked. This information is necessary because the DAU and GMU are not used in the RADIOS Program, but is needed within DEAMAN to be able to match animals and survival rates to a DAU for modeling the population within the DAU. An example of this window follows.

Tip: Notice that under the File menu choice in the File Browser Window are options to copy the records in the browser window to a dBase File, Excel, or the Clipboard. These options provide convenient ways to create tables of data for reports and presentations. Carefully filter the database to obtain the records you want to tabulate, then export them in the desired format for their destination.



The screenshot shows a dialog box titled "Enter DAU and GMU for RADIOS data being imported." with a close button (X) in the top right corner. The dialog has a light beige background. It contains two main input sections. The first section is labeled "Enter a DAU:" and features a dropdown menu with "D-7" selected, followed by a button labeled "GMUs in DAU". The second section is labeled "Enter a GMU:" and features a dropdown menu with "22" selected, followed by a button labeled "DAU for GMU". At the bottom of the dialog, there are three buttons: "Help", "Cancel", and "OK".

Click the “OK” button to proceed, where you now have to match the codes in the Fate Codes file you specified with the minimum set of codes used by DEAMAN. An example follows. Note that there are 3 pages of these codes to consider. For each of the original codes from the Fate Codes file, you must click on one of the 5 buttons to the right. Every one of the original codes has to have a new code assigned. Otherwise, when you click the “OK” button to proceed, you will not be able to import the data because an error message will appear informing you that you failed to provide a code at least one of the original fates.

The dialog box titled "Standardized Fate Codes" has three tabs: Page 1, Page 2, and Page 3. Page 1 is selected and contains 10 rows of fate codes. Each row has a label for the fate and five radio button options: Alive, Predation, Harvest, Other Mortality, and Censored.

Fate =	Fate Description	Alive	Predation	Harvest	Other Mortality	Censored
Fate = 1	1 - Coyote Predation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fate = 2	2 - Bobcat Predation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fate = 3	3 - Lion Predation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fate = 4	4 - Eagle Predation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fate = 5	5 - Unknown Predator	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fate = 6	6 - Starvation	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fate = 7	7 - Illegal kill	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fate = 8	8 - Road kill	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fate = 9	9 - Hunter kill	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Fate = 10	10 - Accident, such as fence death	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

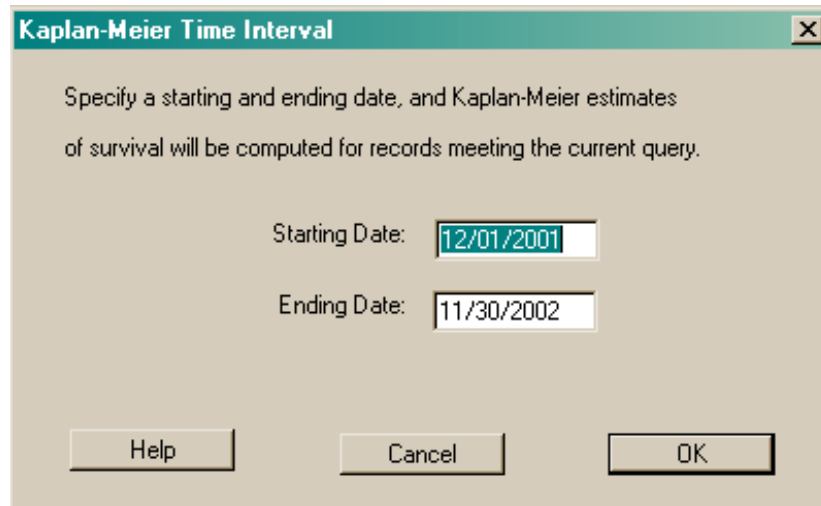
At the bottom of the dialog box are three buttons: Help, Cancel, and OK.

When you have completed specifying the codes on each of the tabbed pages, select “OK” to proceed, and the data will be imported into DEAMAN.

To generate survival estimates from the data stored in the RADIOS.DBF file of DEAMAN, you must select a set of radio-tracking records for animals that you want to estimate survival from. To do this, select the menu choice Query, and you will find a filter creation window opened up. In this filter creation window, define a filter to select the records for the DAU that you want to obtain survival estimates for. Do not specify time intervals, because this will come with the next step of the process. However, you will likely want to select just certain age and/or sex classes, e.g., only fawns, or only adults does. Next, select the menu choice “Survival Estimates” shown at the top of the RADIOS browser window. The following window will appear. You are being asked to enter the time period over which you want to compute survival estimates with the Kaplan-Meier survival estimator that is built into DEAMAN.

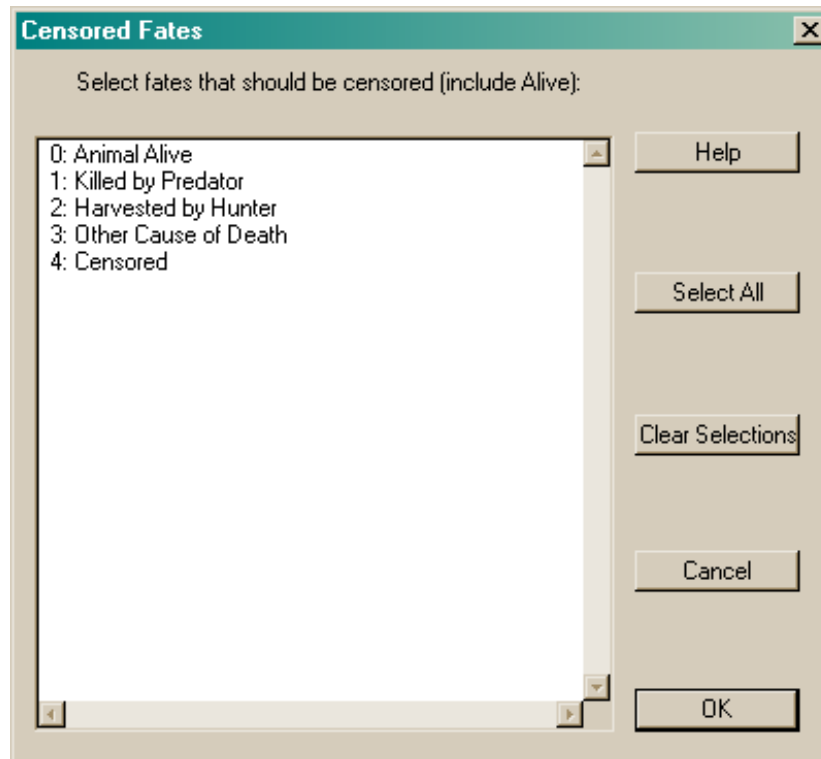
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Typically, as the example in the window shows, you would want to compute survival from immediately post-harvest to 1 year later.

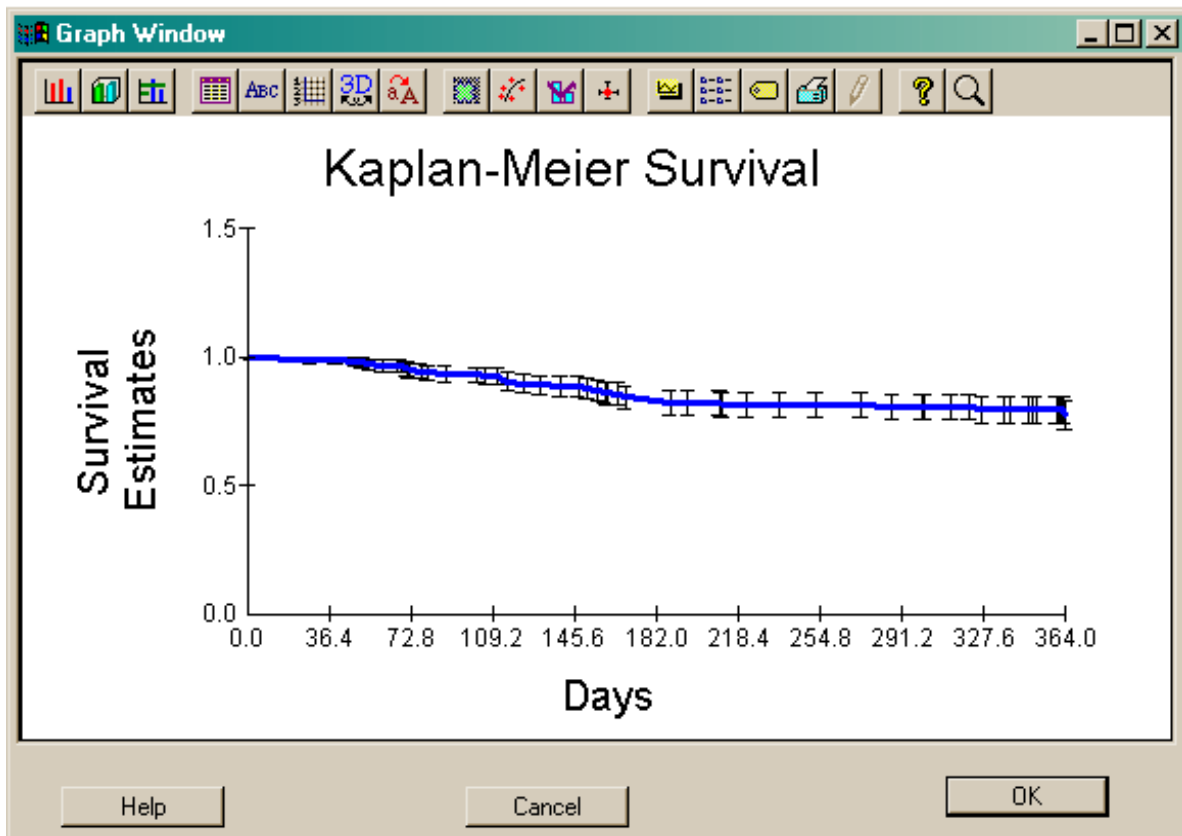


The image shows a dialog box titled "Kaplan-Meier Time Interval". Inside the dialog, there is a text instruction: "Specify a starting and ending date, and Kaplan-Meier estimates of survival will be computed for records meeting the current query." Below this text are two date input fields. The "Starting Date" field contains the text "12/01/2001" and is highlighted with a blue selection box. The "Ending Date" field contains the text "11/30/2002". At the bottom of the dialog box are three buttons: "Help", "Cancel", and "OK".

Note that the above window assumes that you have filtered the Radios database so that only records for animals of interest are available to estimate the Kaplan-Meier survival rate. When you click "OK" to proceed, a dialog window showing the progress of reading the records from the data file will appear, and then disappear when the file has been process. The next dialog window requests how to handle the animal's fates.



You are being asked to select the fates that should be censored, i.e., considered alive at the time that the animal is removed from the sample. As an example, if you want to estimate non-hunting mortality, i.e., only animals that die from causes other than hunting, then you would specify animals that died from "Harvested by Hunter" as censored. Then, when the animal died, it is removed from the sample as if still alive, rather than treated as a mortality. You would almost always select the code "Censored" to be removed from the analysis, although you might want to remove these animals prior to this step by using the filter you created earlier. Likewise, always select the "Alive" code as censored – in this case the animals are still alive! After you select the appropriate codes by clicking on them, click on "OK" to proceed. A dialog window showing progress in reading the Radios file is again shown. When all the data have been processed, 2 overlapping windows appear. The top window is a graphical display of the Kaplan-Meier survival estimate through time, along with confidence intervals on the survival estimate.



You will close the graphics window and the underlying tabular display if you click on the “OK” button of the graphics window, so just reduce the graphics window and get it out of the way by clicking on the Bar in the upper right corner to save it for another examination later. Now you can study on the underlying tabular summary of the Kaplan-Meier estimate.

The top of this table will mostly consist of when animals entered the time period of interest, as shown in the following portion of the table.

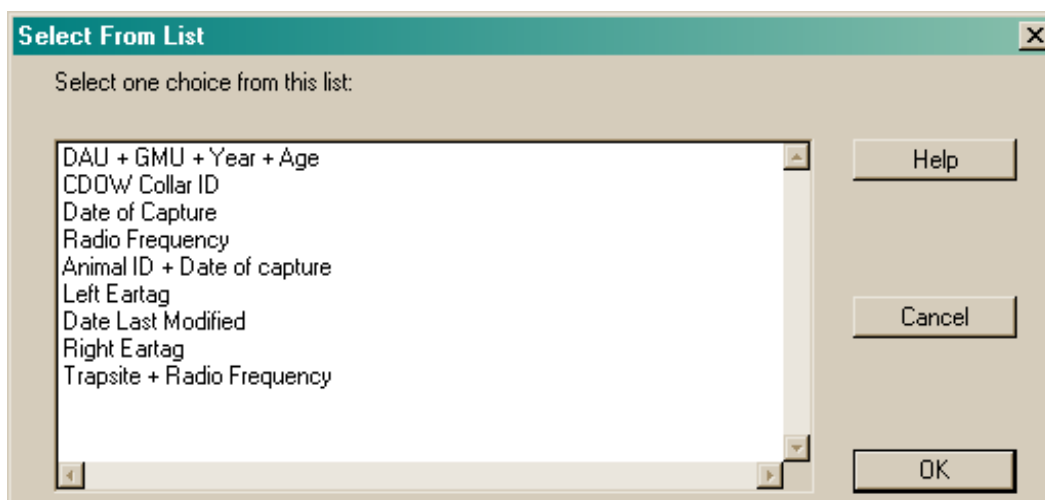
ID	Date	Status	Alive	S-hat	SE(S-hat)	95% LCI	95% UCI
191.013/94	12/01/1994	Entered	1	1.0000	0.0000	1.0000	1.0000
191.020/94	12/01/1994	Entered	2	1.0000	0.0000	1.0000	1.0000
191.041/94	12/01/1994	Entered	3	1.0000	0.0000	1.0000	1.0000

However, it is the bottom of the table that is really of interest, because the last row contains the overall survival rate for the interval.

191.350/94	10/24/1995	Censored	98	0.8060	0.0253	0.7564	0.8556
192.259/94	10/24/1995	Censored	97	0.8060	0.0253	0.7564	0.8556
192.308/94	10/24/1995	Died	96	0.7977	0.0264	0.7460	0.8494
193.072/94	10/24/1995	Censored	95	0.7977	0.0264	0.7460	0.8494
194.990/94	10/24/1995	Censored	94	0.7977	0.0264	0.7460	0.8494
191.270/94	11/03/1995	Censored	93	0.7977	0.0264	0.7460	0.8494
191.630/94	11/03/1995	Censored	92	0.7977	0.0264	0.7460	0.8494
191.657/94	11/03/1995	Censored	91	0.7977	0.0264	0.7460	0.8494
192.860/94	11/03/1995	Censored	90	0.7977	0.0264	0.7460	0.8494
191.471/92	11/05/1995	Censored	89	0.7977	0.0264	0.7460	0.8494

The last animal to die in this example was 192.308/94, and the remaining animals were censored, probably because they lived through the interval. The overall survival rate was 0.7977 with a standard error of 0.0264, and a 95% confidence interval of 0.7460 to 0.8494.

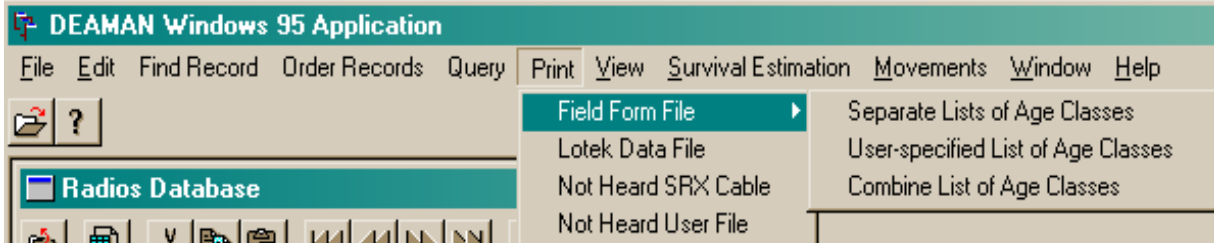
Other options are available in the Radios browser window to examine and organize the records. Under the Find Record menu choice, you can enter values in a filter to locate a particular record in the file. Under the Order Records menu choice, you can select different index files to order the records, as shown below.



Select one of the options to rearrange the order the records in the browser window.

The Print menu choice allows several nifty functions, including generating a field form for recording animal status in the field. The submenu shown below allows the form to be organized by age and sex class of the animals still alive in the Radios database. Another option creates an input file for downloading to a Lotek receiver. The “Not Heard SRX Cable” option allows uploading the frequencies not heard in a Lotek receiver, with all the frequencies originally downloaded now updated to be last heard alive on the date of the file creation. The

“Not Heard User File” allows the user to create a list of frequencies not heard with the receiver, and again all the animals on the original list downloaded to the receiver will be updated to have last been heard on the date the file was created.



The View menu choice lets you switch between a browser table and the data form which is the default view.

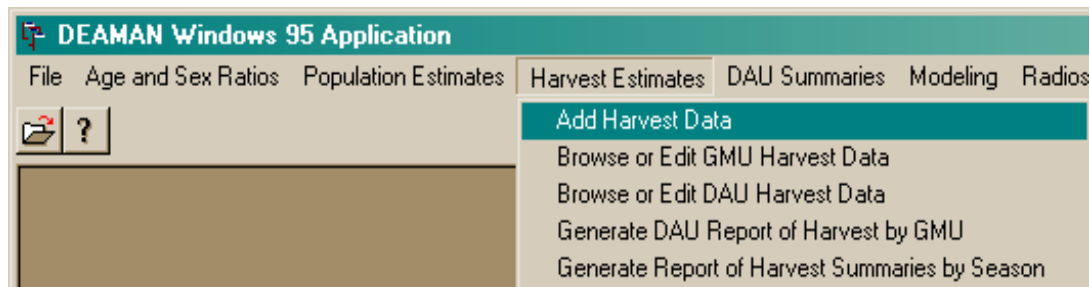
The Movement menu choice is presently not implemented, but the plan is to implement the movement graphics capability of the RADIOS program in DEAMAN.

Importing Data

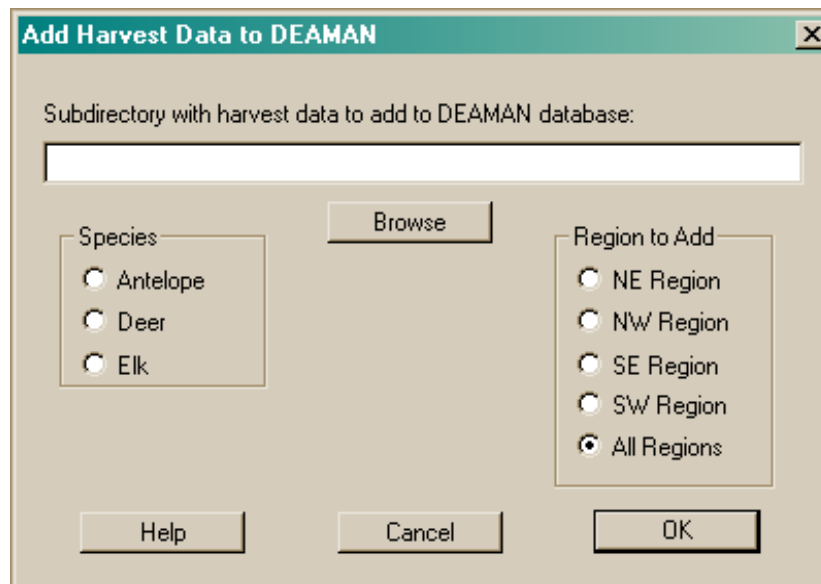
Once data for a DAU and year combination have been entered for age and sex ratios, quadrat counts, or line transects, others would like access to the data. This section describes how to import data supplied by others, including estimates of harvest generated centrally.

Harvest estimates

Estimates of harvest for each species for each year by season are generated centrally by CDOW. Each estimate includes its standard errors and 95% confidence bounds. Files for deer, elk, and pronghorn are supplied separately. To import the annual estimates into DEAMAN, select the menu choices shown below.



The following dialog window will appear.



You are being asked to specify the subdirectory where the harvest files from Denver are stored. To select a subdirectory, use the Browse button. DEAMAN figures out which file to read from this subdirectory based on the species radio button on the left side of the screen. Therefore, you

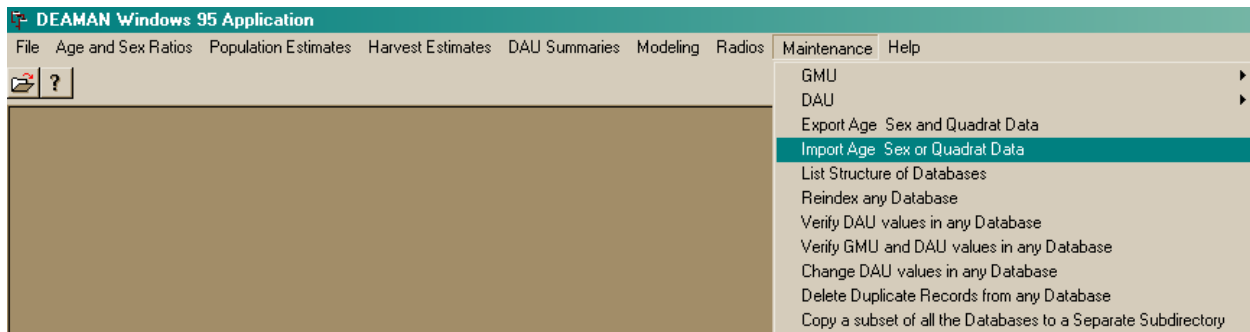
have to click one of these buttons. Finally, you can elect to import all the harvest data, or just the data for a particular region. With the size of modern computer hard drives, you will probably want to import all the harvest data for each of the primary species. To import data for all three species, you will have to repeat the process 3 times.

Once the harvest data are imported, you are done. No more analysis is required to view the summaries of harvest data available in DEAMAN.

Harvest estimates are computed according to the formulae given in White (1993), with a copy of this paper included here as Appendix II.

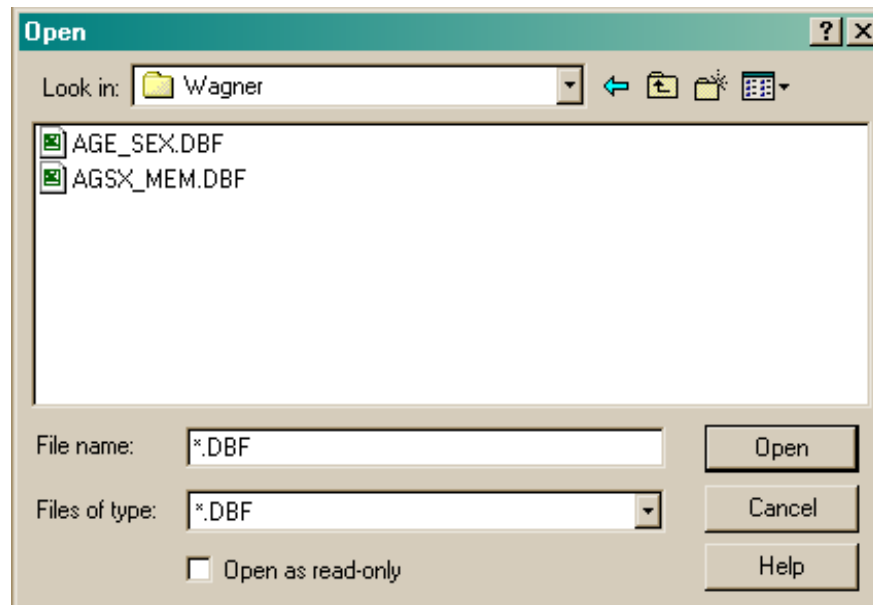
Age and sex ratio data from other users

Age and sex ratio data are imported from files supplied by other users of DEAMAN. To import age and sex ratio data, select the menu choices shown below.

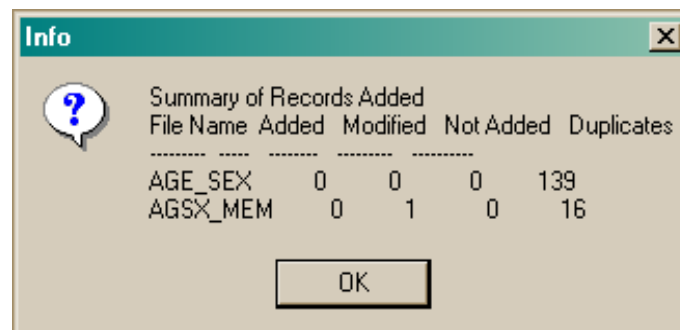


You will be asked to select a file of age and sex ratio data for importing. Note that age and sex ratio data occur in two files in DEAMAN. The AGE_SEX.DBF file contains the raw counts, whereas the AGSX_MEM.DBF file contains information about the surveys, plus contains the memos in a separate file named AGSX_MEM.FPT. All three of these files have to be in the subdirectory for you to import all the age and sex ratio data. In particular, the files AGSX_MEM.DBF and AGSX_MEM.FPT are both required to be able to import the age and sex memo data.

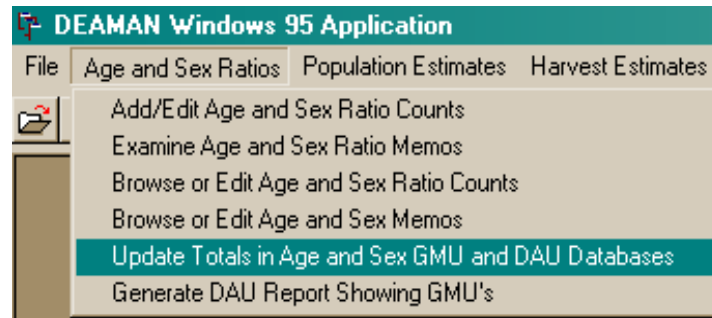
Note, however, that you will not see the AGSX_MEM.FPT file when you use being asked to locate these files. Rather, a filter is set to only show the files with the DBF extension. So, as an example, the following window is showing a correct subdirectory that contains the necessary files, even though AGSX_MEM.FPT is not visible. You can verify that all the files are present in the subdirectory by clicking on the arrow to the right of the "Files of type:" box and changing this to "All Files (*.*)".



Select either of the AGE_SEX.DBF or AGSX_MEM.DBF file, and click the “Open” button. DEAMAN will begin importing the data, showing how many records are added, modified, or are duplicates. If records are modified, you will be asked for each of them to verify that the modification is desired. That is, you will be changing existing data in your DEAMAN databases, and you probably don’t want to do that unless you can see what changes are being made. The summary report of the import procedure looks like the following.



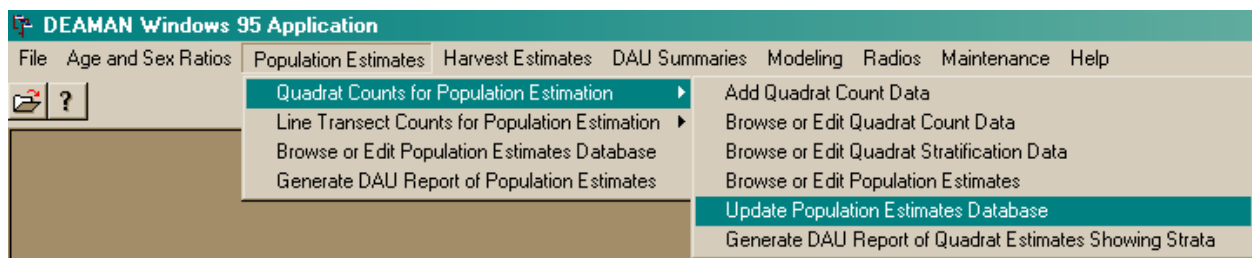
Once the new information has been imported, you will have to update the AGSX_GMU.DBF and AGSX_DAU.DBF files before the new information is incorporated into them. You perform this task with the following menu choices.



Quadrat count data from other users

Quadrat data are imported with the same menu choices as described above for age and sex ratio data, i.e., both age and sex and quadrat data files to be imported can exist in the same subdirectory, and be imported at the same time. The process is identical.

As with age and sex data, once the quadrat data are imported, you must update the higher level summaries stored in the POPEST.DBF file, i.e., incorporate the population estimates from the data just imported into POPEST.DBF. You perform this task with the following menu choices.



Line transect data from other users

Line transect data are also imported via the Maintenance | Import Age and Sex or Quadrat Data menu choices. However, you must be particularly careful with importing line transect data. This is because if you already have the data in your DEAMAN database, the import process does not know this, and will always just add the data to be imported as if it were all new. The net effect is to double your sample size, with each line now represented by at least 2 records, and hence doubling the sample size.

The reason the behavior of the import process is different for line transects from quadrat counts is that quadrats are uniquely identified and only have one record in the QUADRATS.DBF file per quadrat per year. In contrast, multiple line transect records appear for each line, i.e., 1 record for each group observed from the line. Therefore, the import process cannot just replace

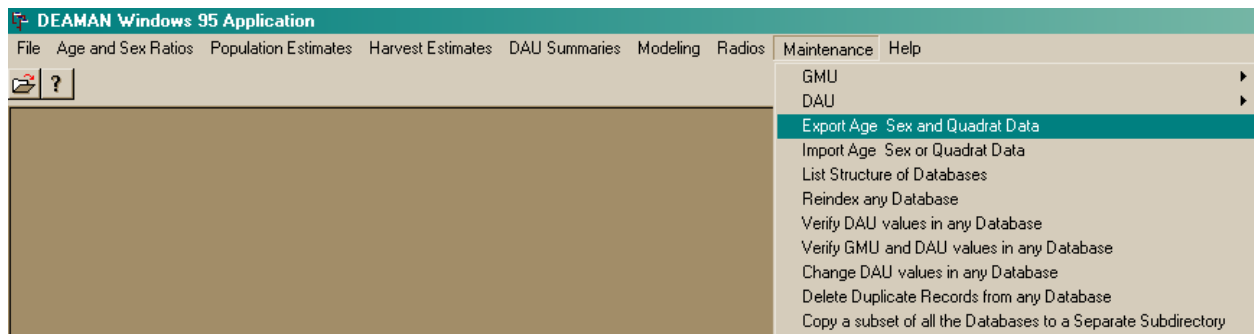
existing records, and thus always adds them onto the LINETRAN.DBF file in the DEAMAN database subdirectory.

Exporting Data to Other Users

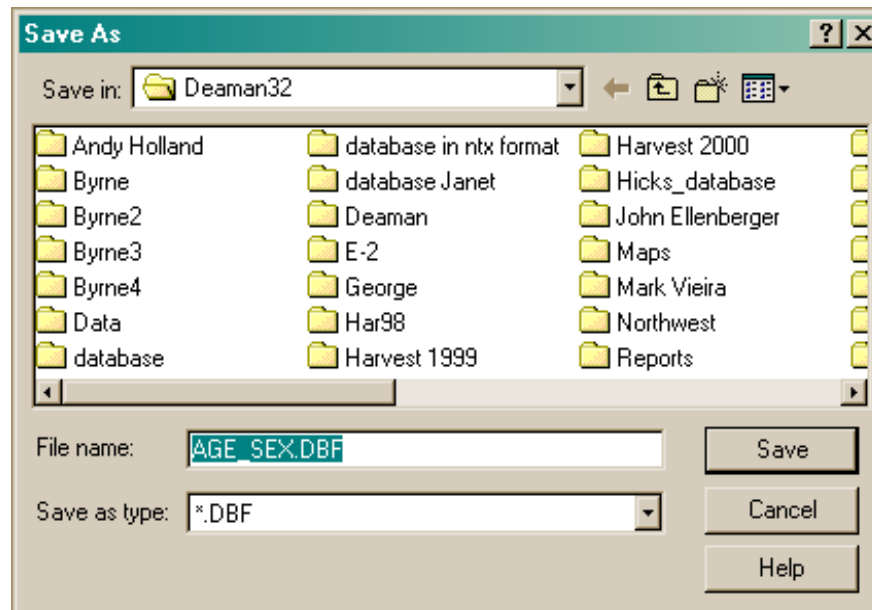
To be able to supply your data to other users of DEAMAN, you want to be able to export your newly entered information as files that others can import. This section describes how to export information from your DEAMAN system to another user's system.

Age and sex ratio data

Age and sex ratio data are exported with the following menu choices.



The first thing that is requested is the subdirectory where the exported files will be stored. You will see a request like the following.



You are being asked to select a subdirectory (a folder), or else create a new one to hold the exported files, one example of which is AGE_SEX.DBF. Note that the right-most yellow icon at the top of the window allows you to create a new subdirectory (folder). If you click this icon, you can provide the name of the new folder, and then open it up for storing the files with your exported data.

The next dialog window is a filter creation window, where you specify what data you want to export. As an example, if you have just finished entering your 2002 age and sex ratio counts, you might want to export all data with YEAR='2000'. When you click the "OK" button on the filter creation window, the export procedure does its work. You should receive an information message saying what data were exported. As an example, I exported all my data for the year 2002 to a subdirectory named "D:\DEAMAN32\NEW FOLDER", and received the following message.



Note that age and sex ratio data were exported, as well as quadrat count data. Had line transect data been available, they also would have been exported. You might not want all these files, so if you do, just delete the excess one.

To actually send your data to another user, the best strategy is to use the winzip utility to zip the files together into a single file, and send that. Don't forget that you have to send all of the age and sex files created in the export subdirectory. For example, from the above export, the following files are present.

Name ▲	Size	Type	Modified
AGE_SEX.DBF	209 KB	DBF File	7/7/2002 1:09 PM
AGSX_MEM.DBF	16 KB	DBF File	7/7/2002 1:09 PM
AGSX_MEM.FPT	283 KB	FPT File	7/7/2002 1:09 PM
QUADRATS.DBF	4 KB	DBF File	7/7/2002 1:09 PM

Note that 3 files are needed to export the age and sex data, and only 1 file for the quadrat count data. Be sure to send all 3 age and sex files to your intended destination, or you'll be hearing back from the recipient with a disappointing message.

Quadrat count data

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Export of quadrat count data is accomplished exactly the same as with age and sex ratio data. See the description above for this process.

Line transect data

Export of line transect data is accomplished exactly the same as with age and sex ratio data. See the description above for this process.

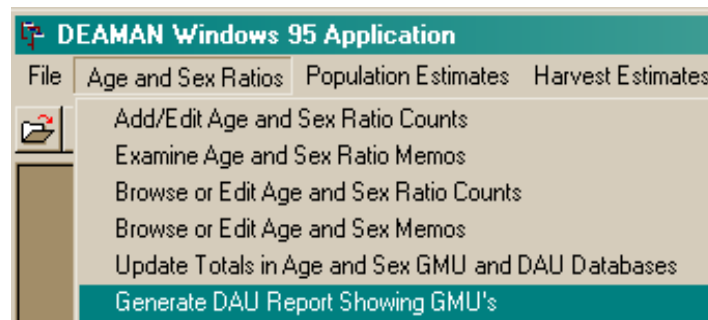
Generating Summaries of Data

Tabular summaries by GMU

Some summaries of data by GMU are available in DEAMAN. However, generally summaries are provided by DAU because this is the spatial unit that management recommendations are based upon. That is, population models are constructed for a DAU, not a GMU. The GMU level summaries are mostly for checking data, and not good for much else.

Age and sex ratios


Summaries of the age and sex ratios within a DAU can be obtained with the following menu choices.



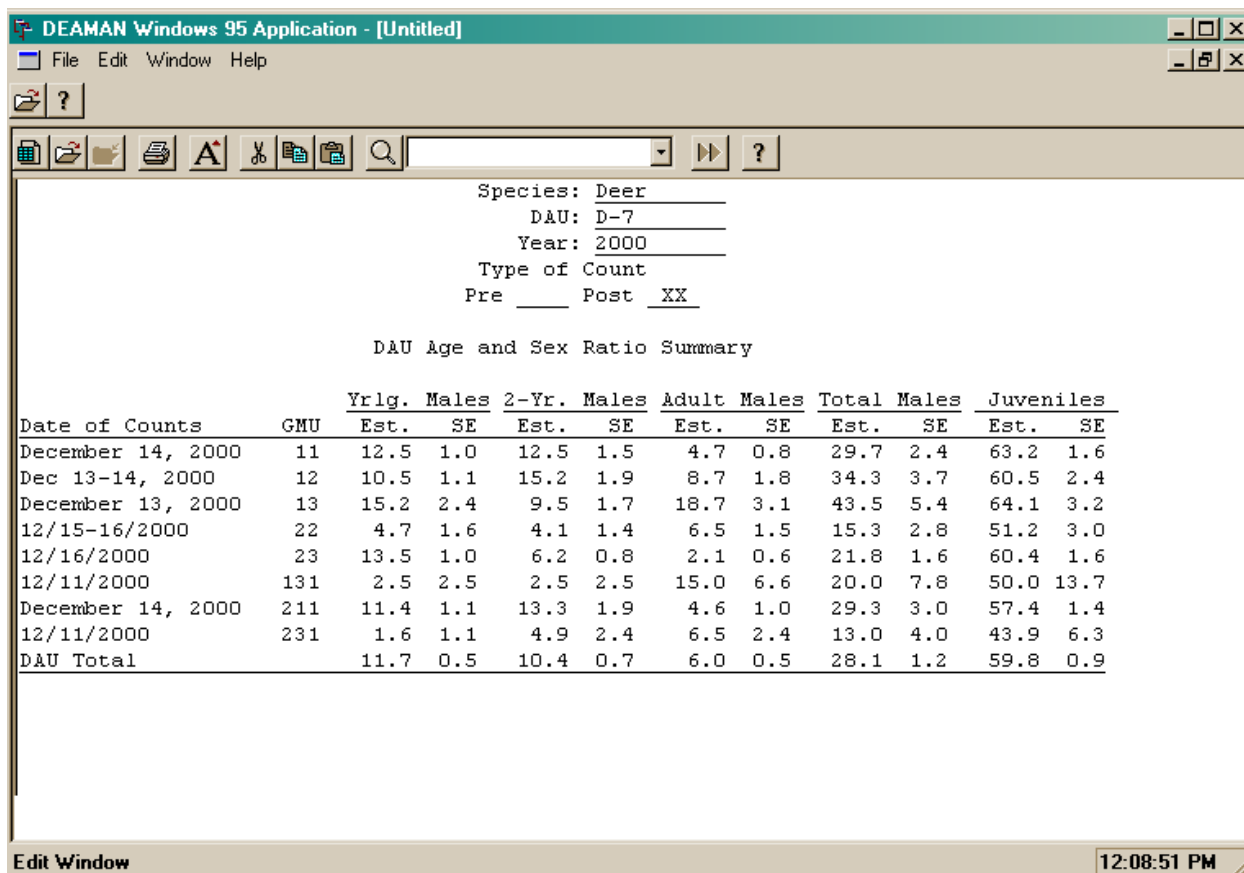
⊗Tirade: Population models are constructed for DAUs, not GMUs. Why then are data only collected on a portion of a DAU when inferences are to be made to the entire DAU from a population model based on these data? Likewise, why would one portion of a DAU be managed under one harvest scenario, and another portion under a different harvest scenario, and yet a population model is supposed to represent both portions as a single DAU?

You are then presented a dialog window asking for the DAU and year for which to provide the data summary. This dialog window also has a request for a GMU, but this request is just informational: it provides you with a list of available GMUs in this DAU. It doesn't matter which GMU you select, as you will still get the same data summary. The request for year

includes an arrow to list which years are available, i.e., a list of years where age and sex ratio data were collected. If the year you want doesn't appear on this list, no age and sex ratio data were probably collected that year. There are also a set of radio buttons to select the type of age and sex ratio survey you

 Tip: If the year doesn't appear in the list of years obtained by clicking the arrow to the right of the request box, then likely no data are available for that year.

want to summarize, either pre-season or post-season surveys. So, if you select D-7 for 2000 with post-season clicked, you will get the following summary of age and sex ratios by GMU.



DEAMAN Windows 95 Application - [Untitled]

File Edit Window Help

Species: Deer
DAU: D-7
Year: 2000
Type of Count
Pre ☐ Post ☒

DAU Age and Sex Ratio Summary

Date of Counts	GMU	Yrlg. Males		2-Yr. Males		Adult Males		Total Males		Juveniles	
		Est.	SE	Est.	SE	Est.	SE	Est.	SE	Est.	SE
December 14, 2000	11	12.5	1.0	12.5	1.5	4.7	0.8	29.7	2.4	63.2	1.6
Dec 13-14, 2000	12	10.5	1.1	15.2	1.9	8.7	1.8	34.3	3.7	60.5	2.4
December 13, 2000	13	15.2	2.4	9.5	1.7	18.7	3.1	43.5	5.4	64.1	3.2
12/15-16/2000	22	4.7	1.6	4.1	1.4	6.5	1.5	15.3	2.8	51.2	3.0
12/16/2000	23	13.5	1.0	6.2	0.8	2.1	0.6	21.8	1.6	60.4	1.6
12/11/2000	131	2.5	2.5	2.5	2.5	15.0	6.6	20.0	7.8	50.0	13.7
December 14, 2000	211	11.4	1.1	13.3	1.9	4.6	1.0	29.3	3.0	57.4	1.4
12/11/2000	231	1.6	1.1	4.9	2.4	6.5	2.4	13.0	4.0	43.9	6.3
DAU Total		11.7	0.5	10.4	0.7	6.0	0.5	28.1	1.2	59.8	0.9

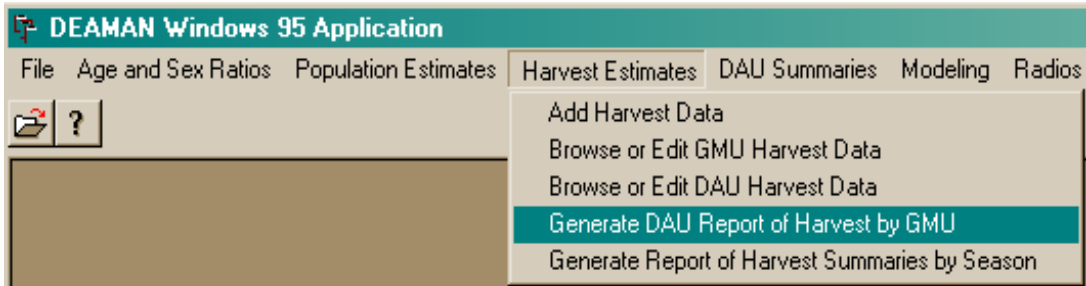
Edit Window 12:08:51 PM

As can be seen in the above window, there are a number of menu choices and task buttons to manipulate the data presented on the screen. In particular, you can highlight the contents of the screen and then copy the text to the clipboard for pasting into a Word document, print the screen directly, or change the font and text alignment to change the "look" of the material. You are also allowed to edit the text and add material to this window, i.e., this presentation window is basically a low-level text editor. You can change the font, italicize or bold text, underline or strikeout text, etc.

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Harvest estimates


Estimates of total harvest (i.e., across all seasons) can be obtained by GMU for a particular DAU by selecting the following menu choices.



This selection results in a request for the DAU to summarize, which then leads to a scrollable screen that you can examine. Because the estimates are across all years, the amount of information is considerable. A partial example for D-7 follows.

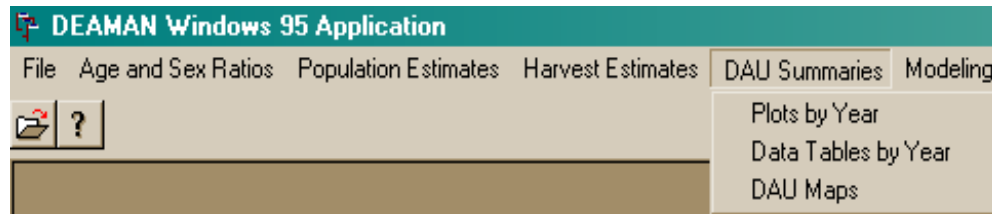
Page 5


Mule Deer Harvest Estimates for DAU D-7 - White River.								
Year	GMU	Parameter	Total Males	Total Females	Total Young	Total Harvest	Total Hunters	Per. Suc.
1989	11	Estimate	1221	643	46	1913	2835	67.5
		Lower 95% CI	1082	585	23	1763	2646	
		Upper 95% CI	1359	700	68	2062	3023	
	12	Estimate	647	196	27	871	2028	42.9
		Lower 95% CI	546	154	9	762	1859	
		Upper 95% CI	747	237	44	979	2196	
	13	Estimate	1025	84	2	1111	2261	49.1
		Lower 95% CI	898	56	-1	981	2076	
		Upper 95% CI	1151	111	5	1240	2445	
	22	Estimate	2227	1512	257	3996	6989	57.2
		Lower 95% CI	2041	1396	161	3792	6706	
		Upper 95% CI	2412	1627	352	4199	7271	

 Tip: Often a more presentable table of GMU values can be obtained by browsing the appropriate GMU file, filtering the file to just view the information desired, and then using the File | Copy to Excel menu choice to copy the data to Excel. The AGSX_GMU.DBF and HARV_GMU.DBF files contain GMU-level data. In Excel, you can do the manipulations you desire to get the necessary summaries, and then copy the Excel table to Word for incorporation into a more professionally appearing table than the DEAMAN summaries provide.

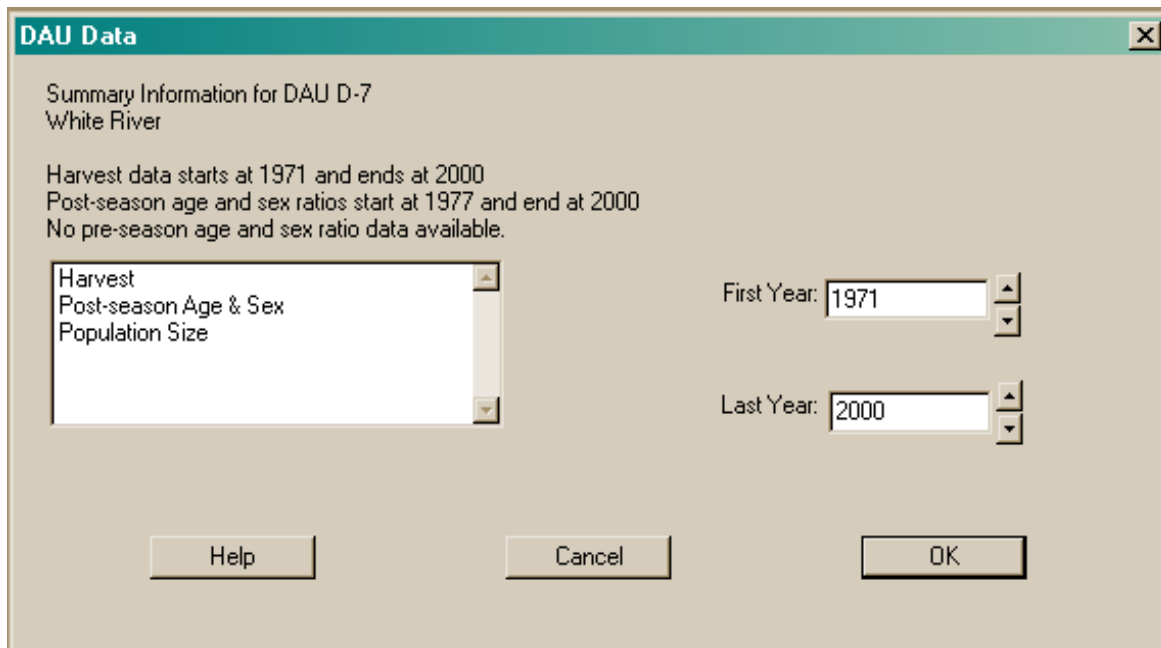
Graphical Summaries by DAU

Most of the DAU-level data summaries appear under the DAU Summaries menu choice, as shown below. You can obtain graphs of data by time, as well as tables of values by time.



 Tip: An easy way to get DAU data is to open a DAU file and filter or query the file so that you only view the data you desire. The files AGSX_DAU.DBF, HARV_DAU.DBF, and POPEST.DBF contain DAU-level summaries. After opening one of these files in the file browser, and setting up a filter to only select the data you want to view, use the File | Copy to Excel menu choice to put the data into an Excel spreadsheet. In Excel, you can format the data table as you desire, or also create graphs that may better suit your needs than the graphs created by DEAMAN.

Summaries at the DAU-level of age and sex ratio, population, and harvest estimates are available under the DAU Summaries menu choice. If you select "Plots by Year", you get a dialog window requesting that you enter the DAU for which you want a data summary. Completing that request results in the following dialog window.



The image shows a software dialog box titled "DAU Data". It contains summary information for "DAU D-7 White River". The text states: "Harvest data starts at 1971 and ends at 2000", "Post-season age and sex ratios start at 1977 and end at 2000", and "No pre-season age and sex ratio data available." On the left, there is a list box with three options: "Harvest", "Post-season Age & Sex", and "Population Size". On the right, there are two input fields: "First Year:" with the value "1971" and "Last Year:" with the value "2000". At the bottom, there are three buttons: "Help", "Cancel", and "OK".

DAU Data

Summary Information for DAU D-7
White River

Harvest data starts at 1971 and ends at 2000
Post-season age and sex ratios start at 1977 and end at 2000
No pre-season age and sex ratio data available.

Harvest
Post-season Age & Sex
Population Size

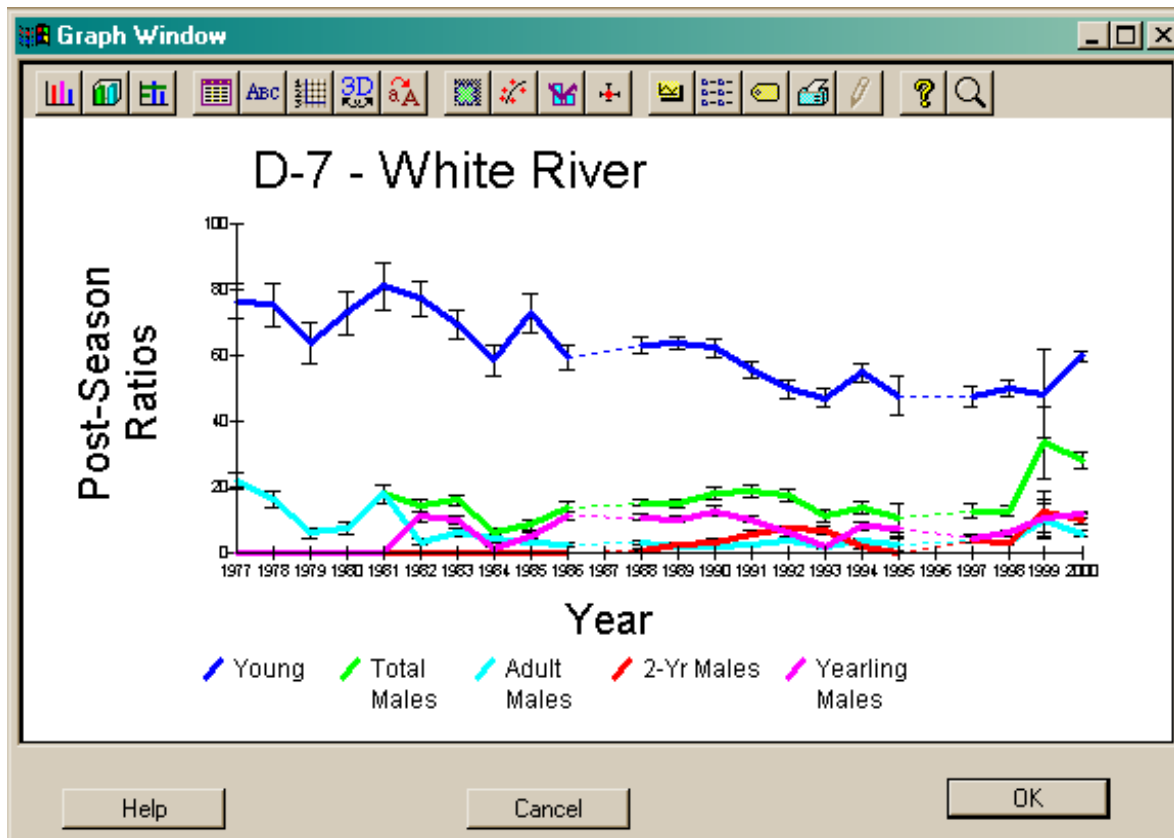
First Year: 1971

Last Year: 2000

Help Cancel OK

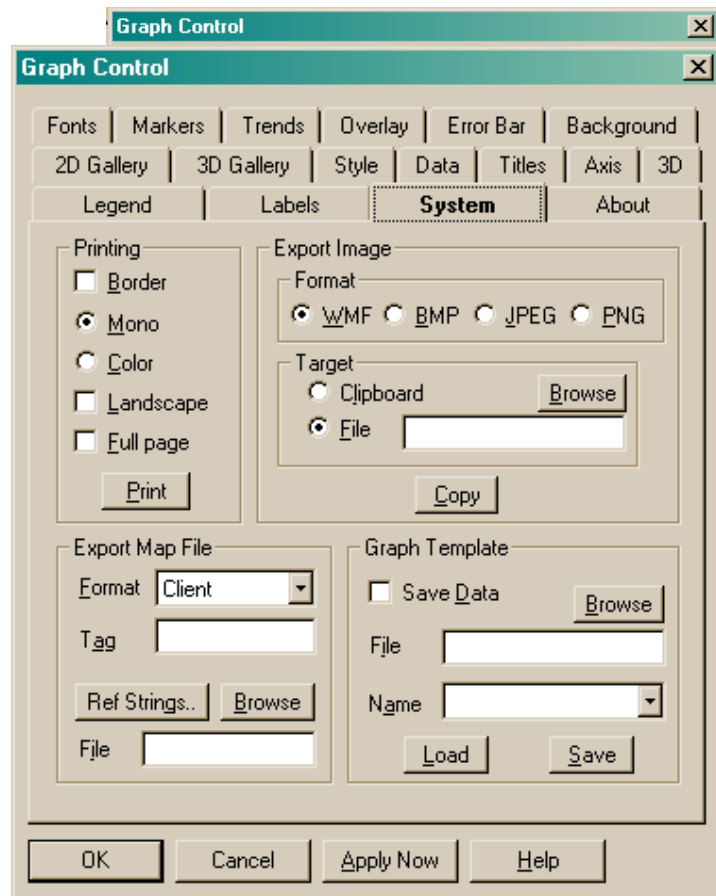
You are being asked to supply 3 pieces of information. First, on the right, which data do you want to summarize: harvest, post-season age and sex ratio, or population size estimates? Had pre-season age and sex ratios been available, these would have been included in this list. When you click on one of the choices, the 2 year boxes change reflecting the start and end year of the kind of data highlighted.

Suppose you select post-season age and sex ratio data, which was collected from 1977 to 2000 (although not in every one of those years). When you click the "OK" button, you get the following graph displayed. Any of the task bar buttons at the top of this window open up a variety of options to manipulate this graph. Each button corresponds to a tab window, so it is not critical which you click on.



For example, clicking on the right-most task bar button results in the following window. You can select the tab that modifies the item on the graph you desire to change. Probably most of the time the default graph is appropriate without changes, so what you really want to do is copy the graph to a Word file where you are writing a report on a particular DAU. To copy the graph to Word, do the following. First, select the System tab from the window shown below.

The System tab results in the window shown at the right. You have a variety of options for the fate of the graph. You can print the graph with the Print button, and specify whether you want a black and white or color graph. You can export the graph as a file, in 1 of 4 formats: WMF (Windows MetaFile), BMP (bit-mapped), JPEG (Joint Photographic Experts Group, probably the most useful format), or PNG (not sure what this does!). Select the format, and then decide whether you want to store the graph as a file for importing into Word, or put it in the clipboard for pasting into Word. If you select the File target, then you will have to specify a file to receive the image, which you can do with the Browse button. Once you have specified the destination, click the Copy button to obtain the image. Click the "OK" button at the bottom of the window to return to DEAMAN.

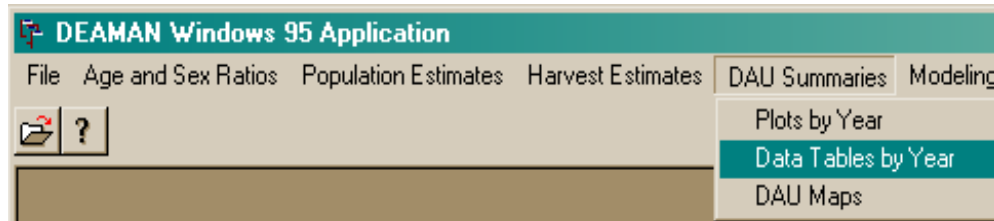


Pre-season age and sex ratios, harvest estimates, and population estimates are all obtained through this series of menus, and all end up with the same graphics windows and capabilities to manipulate and dispose of the graphs. Thus, once you've generated a DAU graph for one kind of data, you've got the knowledge to do so for all the rest. No more excuses for not having highly professional-looking DAU reports.

Tip: The windows to manipulate graphs have a help button at the bottom, but sometimes it does not find the help file named GRAPHPPR.HLP. If you get a message to this effect, select the Yes button to go find the file. It is stored in the \Windows\System or \WinNT\System32 subdirectories, i.e., in the Windows operating system System subdirectory. You can also use the file finding capability of Windows to locate the file.

Tabular Summaries for a single DAU

Summary tables of data from a DAU are obtained with the menu choices shown in the next screen display.



After you select these menu choices, you receive exactly the same sequential set of dialog window as described above for the graphics displays, where you are requested to select the DAU you want to summarize, and then the type of data and years you want to view.

As an example, the tabular summary for harvest data from D-7 would look like the following, where only a portion of the output is on the screen. Each year where estimates have confidence intervals, 3 rows are used to present the results. The first row for each year provides the estimate of each of the parameters listed at the top of the table. The second and third rows provide the lower and upper 95% confidence bounds, respectively.

DEAMAN Windows 95 Application - [Untitled]

File Edit Window Help

Page 2

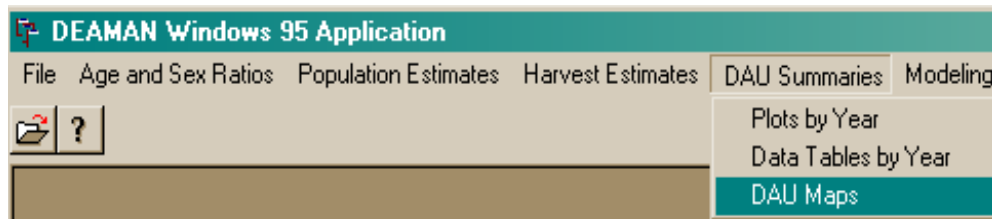
Mule Deer Harvest Estimates for DAU D-7 - White River.

Year	Parameter	Total Males	Total Females	Total Young	Total Harvest	Total Hunters	Per. Suc.
1996	Estimate	6394	656	44	7093	17853	39.7
	Lower 95% CI	6132	589	22	6828	17452	
	Upper 95% CI	6655	722	65	7357	18253	
1997	Estimate	5031	1575	57	6665	18772	35.5
	Lower 95% CI	4796	1439	23	6408	18392	
	Upper 95% CI	5265	1710	90	6921	19151	
1998	Estimate	4285	1655	132	6073	18419	33.0
	Lower 95% CI	4073	1529	87	5840	18052	
	Upper 95% CI	4496	1780	176	6305	18785	
1999	Estimate	3148	1138	60	4346	10004	43.4
	Lower 95% CI	2873	1003	31	4038	9544	
	Upper 95% CI	3422	1272	88	4653	10463	
2000	Estimate	82	37	0	119	136	87.5
	Lower 95% CI	78	37	0	115	132	
	Upper 95% CI	85	37	0	122	139	

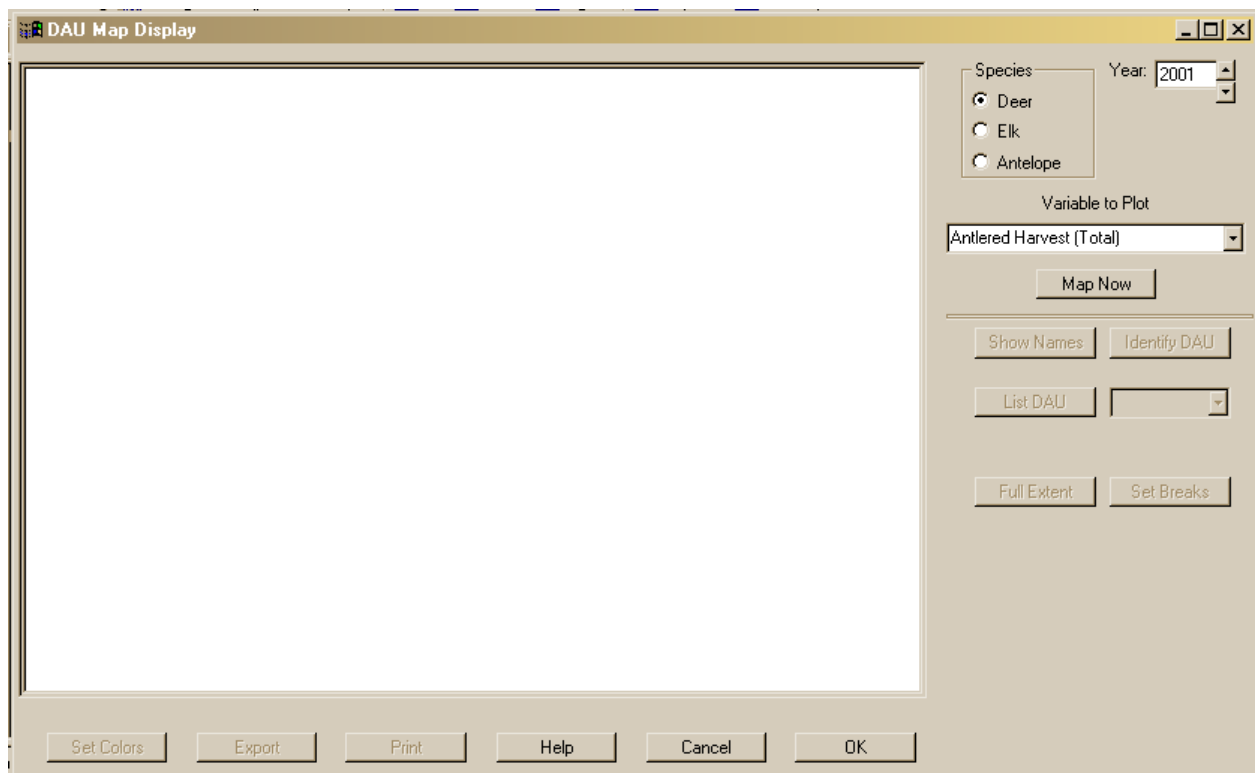
Edit Window 02:09:00 PM

Graphical Summaries for State-wide DAU Estimates

One of the most biologically interesting graphical displays available in DEAMAN is a GIS map of summaries of various variables. You obtain such a display with the following menu choices.



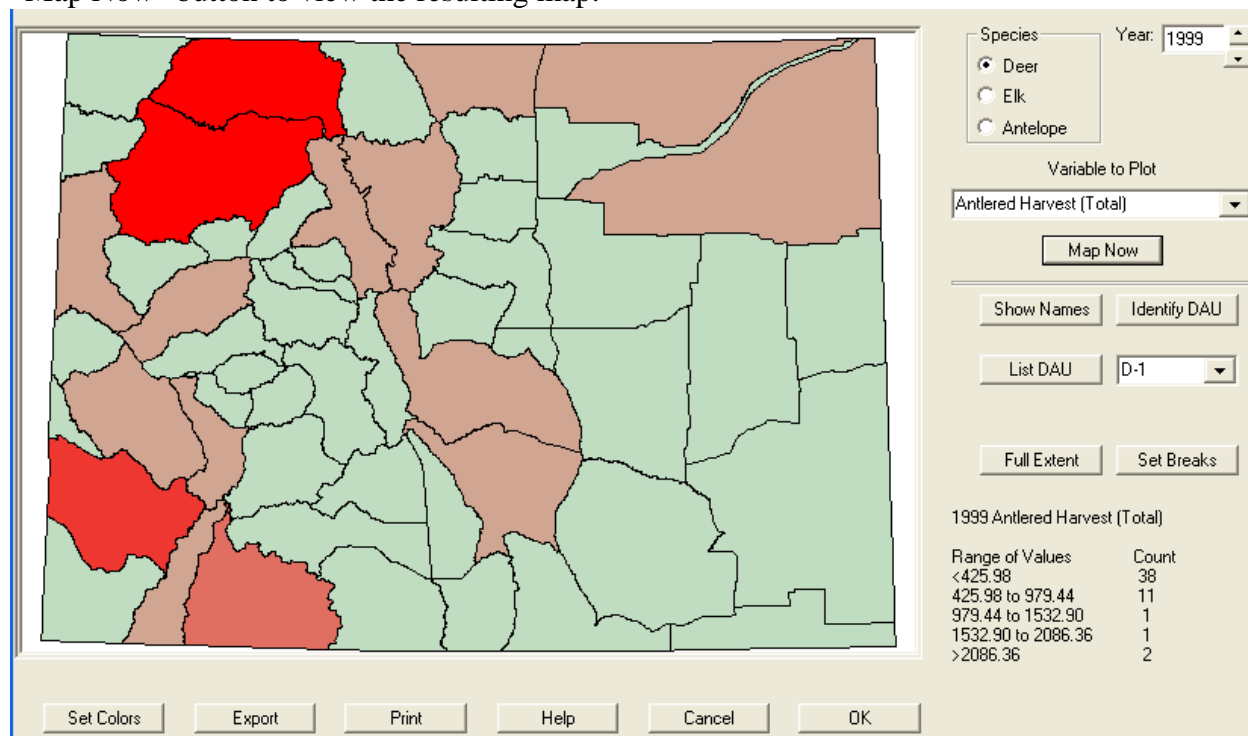
When this selection is made, the following window appears.



You have 3 choices to make to select a map. First, select the species you want to map by clicking one of the 3 radio buttons in the upper right corner. Next, specify the year you want plotted, further right of the species choices. You can increment or decrement the year entry box

with the arrows to the right of the box. Last, select which variable you want to map. The possible choices are shown to the right.

Once you have selected the appropriate choice for each of these 3 selections, click the “Map Now” button to view the resulting map.



The 5 color shades on the map correspond to the intervals specified in the lower right corner of the display. For example, the lightest shade of green corresponds to antlered harvest of <425.98 deer per DAU. The brightest shade of red corresponds to a harvest of >2086.36 deer per DAU. The 3 intermediate colors correspond to the intervals around the intermediate 3 intervals.

Several other useful options are available for manipulating this map. You can have the DAU names shown on the map by clicking the “Show Names” button. To remove the names, click the same button again.

The “List DAU” button will provide the value used to map the DAU shown in the entry box to the right of the button. This combination is useful for determining the exact values of a couple of the DAUs on the map.

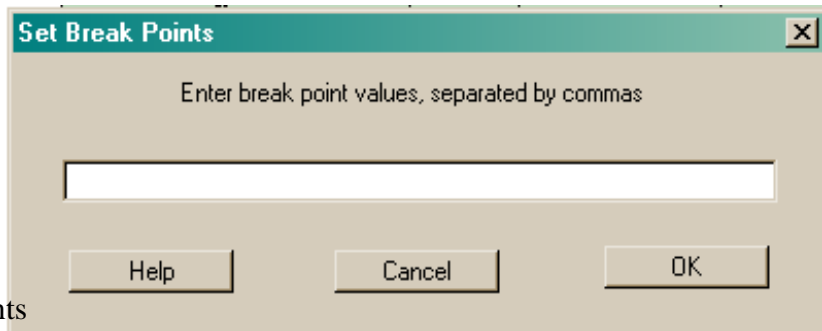
Antlered Harvest (Total)
Antlered Harvest (Total) per mi ²
Antlerless Harvest (Total)
Antlerless Harvest (Total) per mi ²
Hunters (Total) per mi ²
Age Ratios
Sex Ratios
Population Size
Population Density (per mi ²)
Population Survey Density (per mi ²)

Another useful button on the map window is the Print button. You can print the map in either a Landscape or Portrait orientation.

Setting interval boundaries

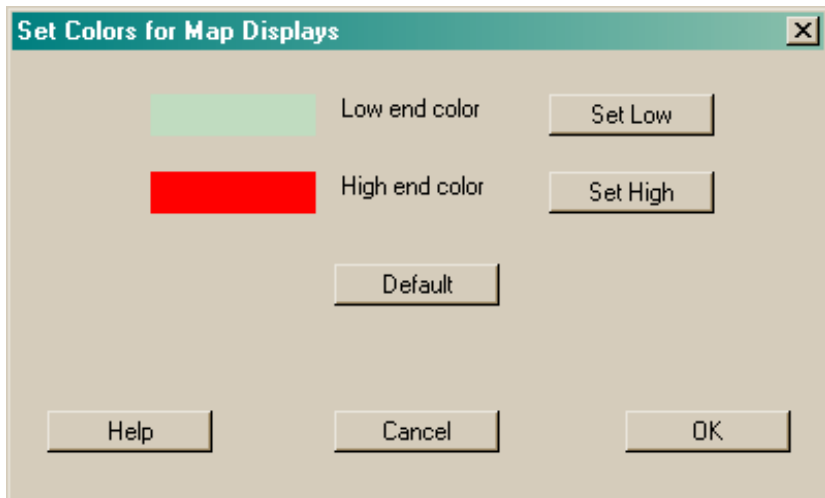
The above map is colored based on the interval boundaries shown in the lower right corner of the display. You can change these intervals by clicking the “Set Breaks” button above the intervals. The dialog window to the right results. In this window, enter the break points (i.e., interval boundaries) that

you want into the entry box, and separate the values by commas. For example, an entry of 400, 500, 600, 700, would result in 5 categories: <400, 400-500, 500-600, 600-700, and >700.



Setting Map Colors

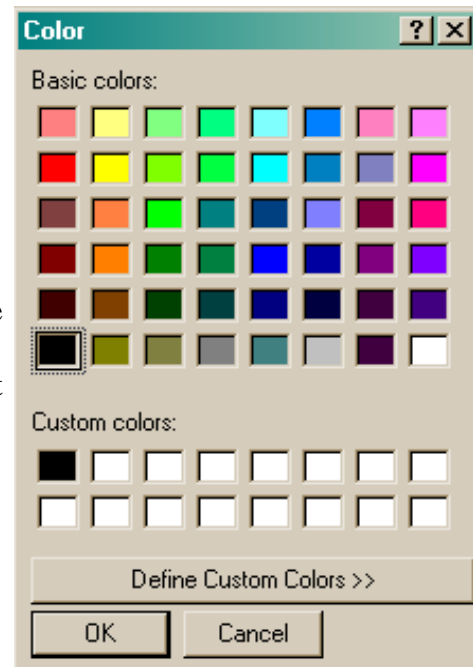
You may want to change the colors on the map. To do so, click the “Set Colors” button in the lower right corner of the map window. The dialog to the right will appear. You can set the low end and high end colors to provide a different set of colors. To set the low end color, click the “Set Low” button, and a new dialog window will appear.



An example of the color dialog window appears to the right. You select the color you want for the low end color by clicking one of the basic colors shown. You can also define your own color with the “Define Custom Colors” button, but you’d be getting pretty fancy if you did. After you’ve selected a color you want, click the “OK” button to return to the original dialog window.

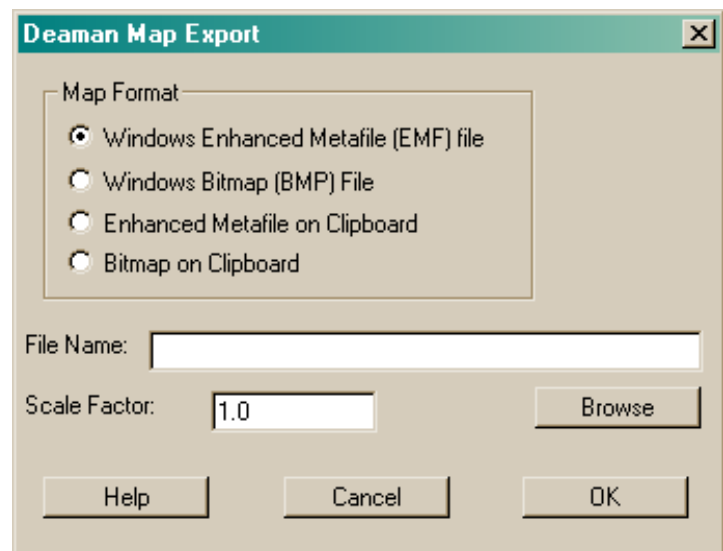
A similar procedure is used to select the color for the high end color. The current values of the low and high end colors are shown on the dialog window, so you can see what you should expect when you return to the map window.

In case you mess up the colors so bad that you can’t get back to the original colors, click the “Default” button to reset the colors to the default values.



Exporting Maps to Word

Typically, you probably would like to have the map exported to a Word document. To do this, click the “Export” button on the lower left portion of the window. The following dialog box will result. Select the format of the file that you want to export the map to by clicking one of the radio buttons. Then enter a file name, which can be done with the Browse button to select a file name through a Windows file dialog window. Finally, you may want to scale the map either larger or smaller, which you can do by entering a value in the Scale Factor entry box. When you’ve completed your choices, click the “OK” button to proceed. The map will be saved to the specified file, and you can then import this file into a Word document.

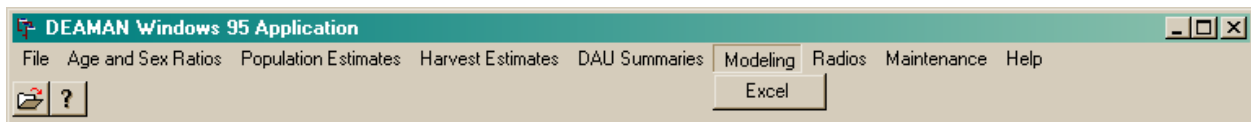


Developing a DAU Population Model

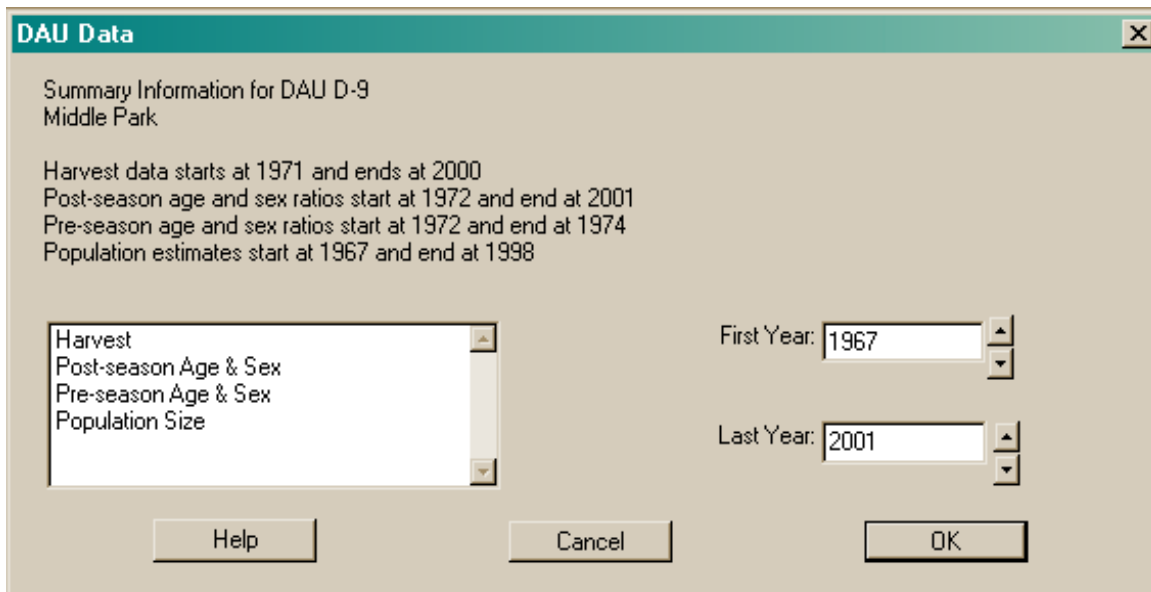
The biggest use of the data stored in DEAMAN each year is in building population models of each DAU for determining the harvest to manage the population close to the DAU objective. This process is simplified in DEAMAN with a procedure to create a simple “First Draft” population model in an Excel Spreadsheet.

Exporting Data to an Excel Spreadsheet

Data on the population in a specific DAU are exported to an Excel spreadsheet with the following menu choices.



After selecting these menu choices, you will be requested to enter a DAU to model. Following entry of this DAU, available data are summarized and a dialog window opened that is asking you what years do you want to include in the model. A summary of the first and last year of data for harvest, pre- and post-season ratios, and population size is provided.



Typically, you would want at least 10 years, and probably up to 15 years of data to be used to model a DAU. However, because of regulation changes or other changes in the population dynamics of the DAU, you might choose to have less than 10 years. By examining the available data in the above dialog window, you can reach a decision and set the appropriate starting and ending years. After you select the years to start and end the model (which can be done by

clicking the up and down arrows to the right of each of the year boxes), data will be placed in an Excel spreadsheet. A partial Excel screen is shown below that illustrates the result.

Population Model for DAU D-9 Middle Park										
	A	B	C	D	E	F	G	H	I	J
1	Population	Model for DAU D-9 Middle Park								
2										
3		Observed Data								
4		Post-Season Ratios								
5		Males:Females		Young:Females		Harvest Data			Population Data	
6	Year	Estimate	SE	Estimate	SE	Young	Males	Females	Estimate	SE
7	1986	19.35	1.53	71.89	3.55	38	984	273		
8	1987	15.54	1.30	77.68	3.61	72	1009	476	11965	2548.936
9	1988	23.61	9.10	61.79	12.50	90	1398	636		
10	1989	13.51	1.09	79.88	2.07	13	1121	186	6417	1326.444
11	1990	23.61	9.10	61.79	12.50	93	1206	874		
12	1991	18.64	1.06	74.01	1.73	79	1112	778		
13	1992	17.93	1.38	56.67	2.04	122	1062	1169	8173	1834.043
14	1993	23.61	9.10	61.79	12.50	10	659	255		
15	1994	15.16	1.05	59.06	1.47	19	793	283		
16	1995	25.76	2.52	48.66	1.98	8	947	249		
17	1996	19.11	1.25	67.09	1.46	7	1072	232	8260	1773.86
18	1997	19.97	1.36	41.25	1.35	14	959	268		
19	1998	28.95	4.32	61.18	3.69	24	892	509	11016	1693.009
20	1999	39.97	4.30	68.31	5.29	61	613	723		
21	2000	38.82	3.83	46.74	3.67	0	33	18		
22	2001	34.26	5.87	50.87	4.14					

Values in green in this spreadsheet are estimates of the mean values for years when no data were collected. Thus, the green 23.61 that appears 3 times in the above spreadsheet is the mean male:female sex ratio across the years 1986 to 2001 when age and sex ratio data were collected. The green SE value of 9.10 is the standard deviation of the sex ratios during this period. The standard deviation of the observed sex ratios is used as a measure of the variation expected in the missing years, because the standard deviation measures the variation of the observed data.

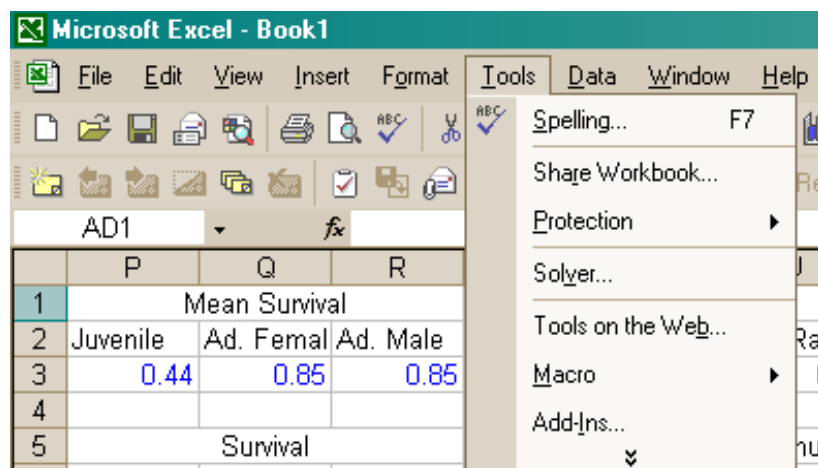
Estimating the Model Parameters from Observed Data

The Excel spreadsheet model is set up to optimize the parameter values based on the methods described in White and Lubow (2001), a copy of which is included here as Appendix III. This process starts with optimizing on the basic survival rates, shown in another portion of the Excel screen, and illustrated below.

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Microsoft Excel - Book1								
File Edit View Insert Format Tools Data Window Help								
AD1 fx								
	P	Q	R	S	T	U	V	W
1	Mean Survival							
2	Juvenile	Ad. Femal	Ad. Male	Initial Pop./10000		Sex Ratio (% female)		
3	0.44	0.85	0.85	0.924		0.5		
4								
5	Survival			Winter	Pre-hunt Population			
6	Young	Ad. Female	Ad. Male	Severity	Young	Females	Males	Total
7	0.44	0.85	0.85	1.00				
8	0.44	0.85	0.85	1.00	3456	4871	1559	9886
9	0.44	0.85	0.85	1.00	2409	4438	1125	7972
10	0.44	0.85	0.85	1.00	2795	3686	157	6638
11	0.44	0.85	0.85	1.00	1715	3571	-303	4983
12	0.44	0.85	0.85	1.00	1358	2573	-1030	2901
13	0.44	0.85	0.85	1.00	391	1739	-1636	495
14	0.44	0.85	0.85	1.00	111	442	-2327	-1774
15	0.44	0.85	0.85	1.00	-69	159	-2572	-2482
16	0.44	0.85	0.85	1.00	-197	-149	-2948	-3294
17	0.44	0.85	0.85	1.00	-435	-405	-3436	-4276
18	0.44	0.85	0.85	1.00	-378	-658	-4020	-5057
19	0.44	0.85	0.85	1.00	-865	-897	-4401	-6162
20	0.44	0.85	0.85	1.00	-1456	-1434	-4771	-7661
21	0.44	0.85	0.85	1.00	-1052	-2230	-4963	-8245
22	0.44	0.85	0.85	1.00	-1091	-2144	-4481	-7715

The values in blue at the top of the screen are values that should be estimated by fitting the model to the observed data. This process is accomplished with the Solver function of Excel, available under the Tools menu choice, as shown to the right. If the Solver choice is not available, then you will have to



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use the Add-Ins... menu choice to add Solver to your version of Excel.

The goal, as described in White and Lubow (2001), is to minimize the sum of the sum of the deviances and penalties for the model, the value shown in red in the display screen below.

Microsoft Excel - Book1

File Edit View Insert Format Tools Data Window Help

File Edit View Insert Format Tools Data Window Help

AD1

	X	Y	Z	AA	AB	AC	AD	AE	AF	AG
1		Wounding Loss								
2		Antlerless	Antlered			Total	Deviance	Penalty		
3		0.1	0.1			5400335.68	5400336	0		
4									Model Checks	
5		Post-hunt Population			Male:Female Ratios		Pop. Size		Male Harvest Rates	
6	Young	Females	Males	Total	Estimate	Deviance	Deviance		Age 1+	Age 2+
7	3473	4832	935	9240	19.35				0.51	
8	3377	4347	449	8173	10.33	16.083	2.213		0.69	1.27
9	2310	3739	-413	5636	-11.05				1.42	3.66
10	2781	3482	-1076	5186	-30.91	1660.689	0.861		24.97	-3.19
11	1613	2610	-1629	2593	-62.44				-2.85	-1.32
12	1271	1717	-2253	735	-131.23	19989.393			-0.97	-0.80
13	257	453	-2804	-2094	-618.51	212695.617	31.336		-0.61	-0.55
14	100	161	-3052	-2791	-1891.16				-0.28	-0.28
15	-90	-152	-3444	-3686	2263.15	4583627.786			-0.30	-0.31
16	-206	-423	-3989	-4618	942.99	132480.674			-0.31	-0.32
17	-443	-660	-4615	-5718	699.22	296027.656	62.096		-0.30	-0.32
18	-393	-953	-5075	-6422	532.41	141971.410			-0.23	-0.24
19	-891	-1457	-5382	-7730	369.45	6212.420	122.598		-0.20	-0.21
20	-1523	-2230	-5445	-9197	244.21	2256.071			-0.13	-0.13
21	-1052	-2250	-4999	-8301	222.20	2292.496			-0.01	-0.01
22	-1091	-2144	-4481	-7715	209.01	886.282			0.00	0.00

As described by White and Lubow (2001), complex model structures can be developed with this spreadsheet modeling approach.

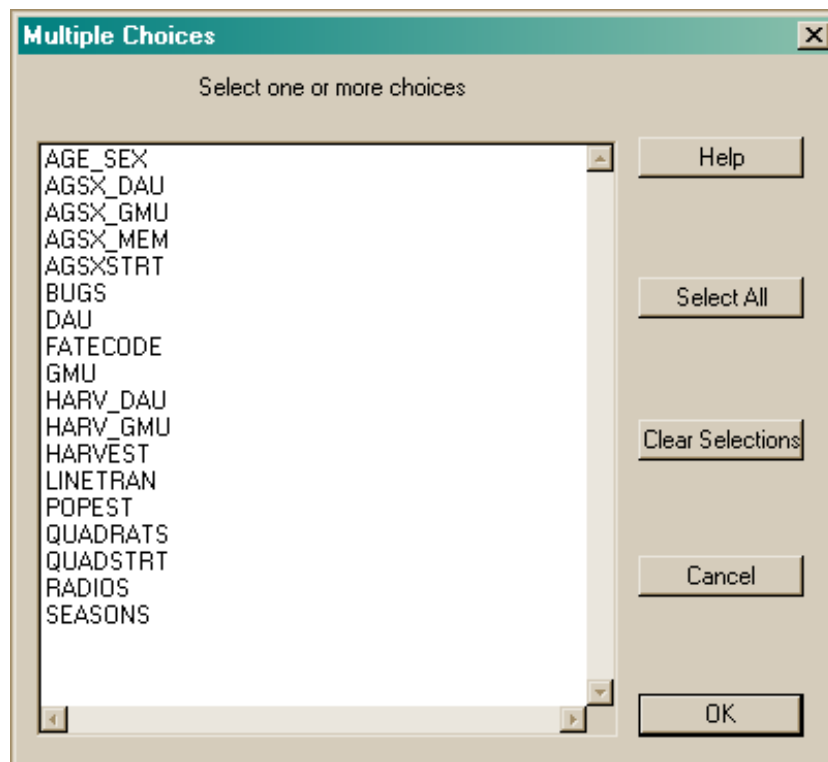
Maintenance of DEAMAN Databases

Various “bad” things happen with the DEAMAN databases, and in this section, I describe tools to correct common problems.

Reindexing Existing Files

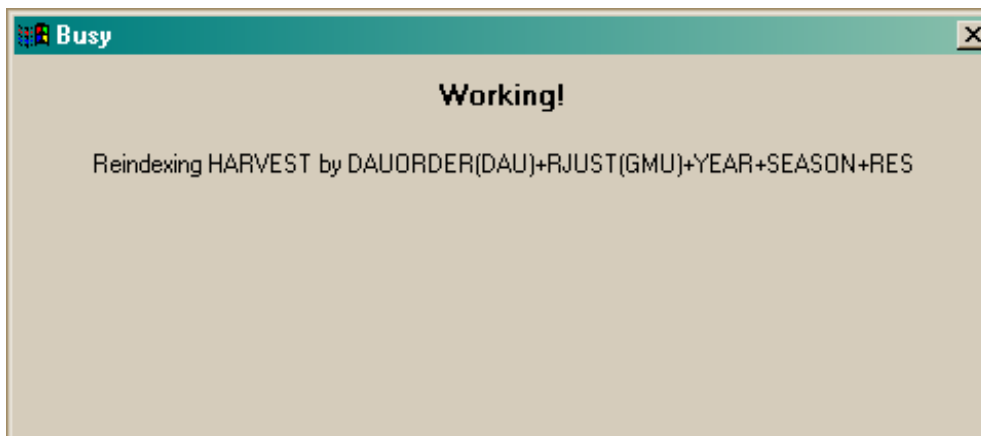
All the databases in DEAMAN depend on index files with the extension “CDX” to order the records in the file. Because of complexity of the interactions between DEAMAN manipulation of these files, Windows memory problems, and hardware malfunctions, phase of the moon, etc., these index files become contaminated for various reasons. Whenever you are sure that data should be available, but don't find any records in the file, or DEAMAN just seems to be behaving poorly, the first remedy is to reindex the index files. To perform this task, select the following menu choices.

Selecting these menu choices results in the following dialog window.



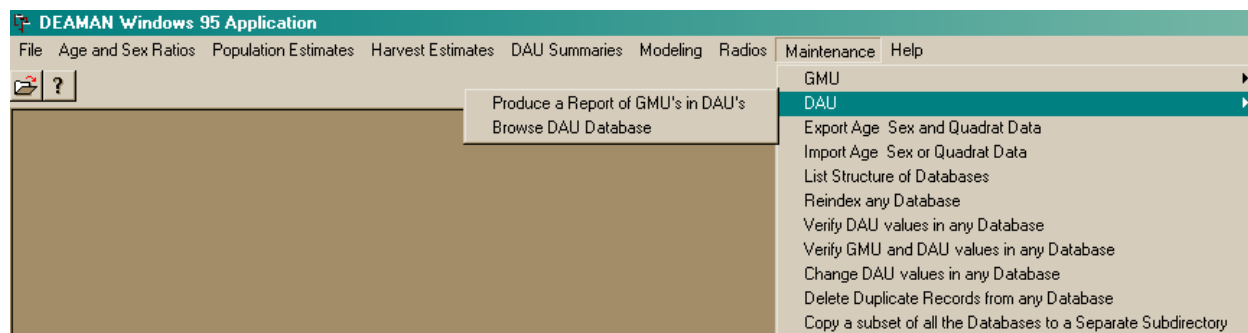
In the above window, you are being asked to select the files that you want to reindex. Commonly, a good choice is to click the “Select All” button, and then click “OK” to reindex all your data files.

A series of progress messages will appear and disappear as files are reindexed. An example is shown to the right for the HARVEST file. The character string at the end of the message is the index string currently being reindexed.

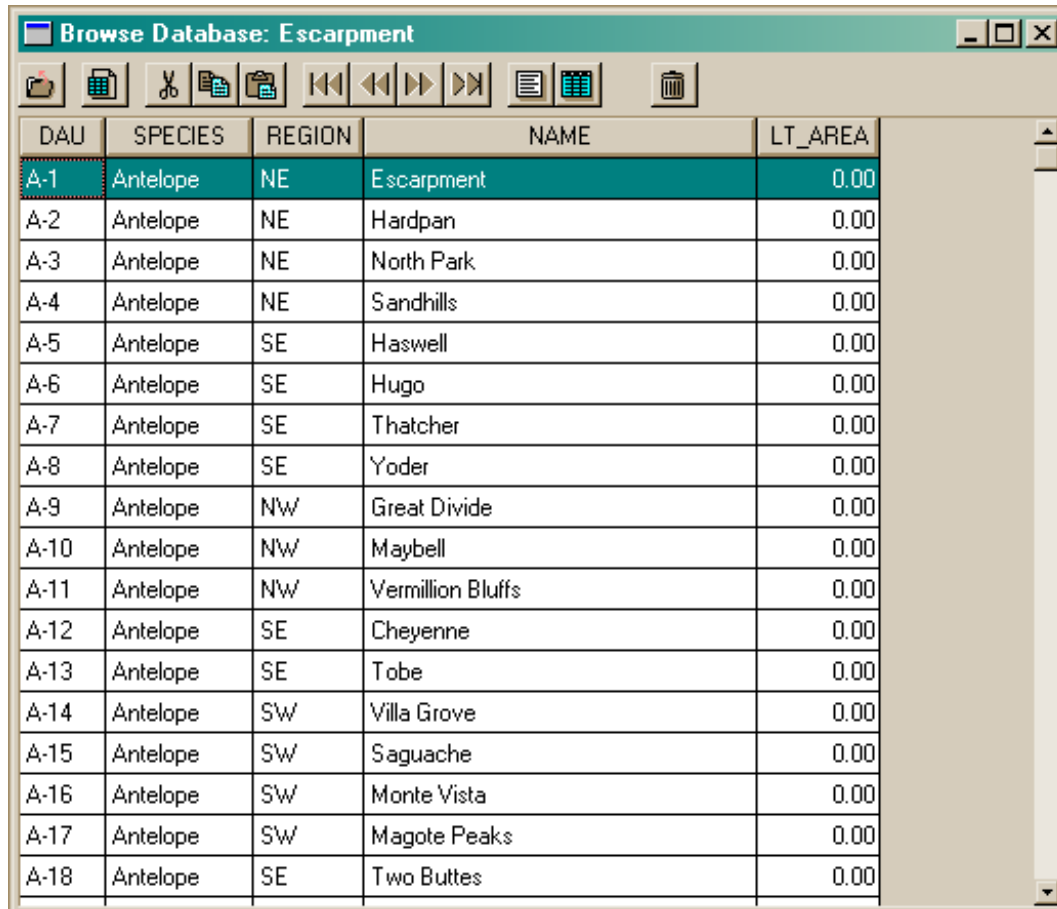


Updating the DAU Database

The DAU database contains information about each of the DAUs defined by CDOW managers. These units change with time as new DAUs are created, or combined. Thus, a procedure is available in DEAMAN to update the DAU database. The Maintenance main menu choice leads to menus to work with the DAU database, as shown below.



I will first discuss the “Browse DAU Database” menu choice, which allows you to edit the contents of this datafile with the usual file browser window. If you select the option shown on the screen above, you are given a chance to create a filter with the usual window. You can select just a subset of the DAUs for viewing (e.g., DAU contains “D” for just deer DAUs), or you can click the “OK” button to not have a filter. An example is shown below. The definitions of most of the variables is obvious, but LT_AREA needs explanation. This variable contains the size of the area in mi^2 that is sampled with line transects. For DAUs not sampled with line transects, the default value is zero.



DAU	SPECIES	REGION	NAME	LT_AREA
A-1	Antelope	NE	Escarpment	0.00
A-2	Antelope	NE	Hardpan	0.00
A-3	Antelope	NE	North Park	0.00
A-4	Antelope	NE	Sandhills	0.00
A-5	Antelope	SE	Haswell	0.00
A-6	Antelope	SE	Hugo	0.00
A-7	Antelope	SE	Thatcher	0.00
A-8	Antelope	SE	Yoder	0.00
A-9	Antelope	NW	Great Divide	0.00
A-10	Antelope	NW	Maybell	0.00
A-11	Antelope	NW	Vermillion Bluffs	0.00
A-12	Antelope	SE	Cheyenne	0.00
A-13	Antelope	SE	Tobe	0.00
A-14	Antelope	SW	Villa Grove	0.00
A-15	Antelope	SW	Saguache	0.00
A-16	Antelope	SW	Monte Vista	0.00
A-17	Antelope	SW	Magote Peaks	0.00
A-18	Antelope	SE	Two Buttes	0.00

A second option under the Maintenance | DAU menu choice is to produce a report of the GMUs in each of the DAUs. This report is produced in the usual memo window, with an example below showing the first 2 DAUs in DEAMAN.

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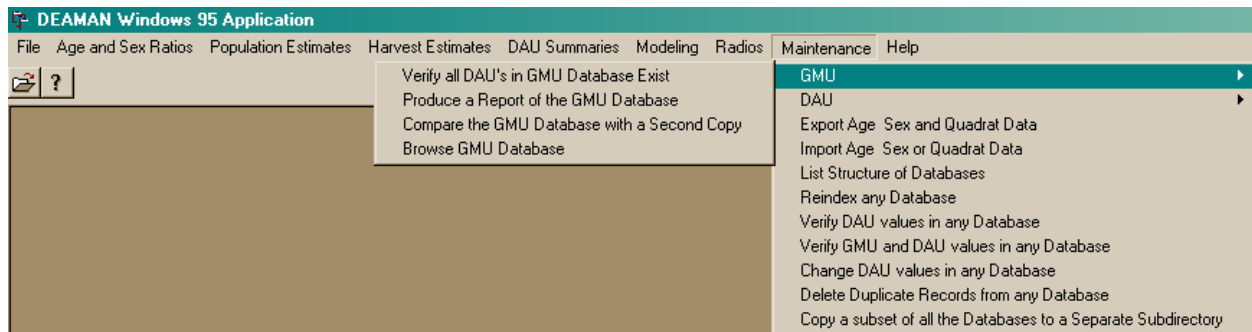
DAU A-1, Antelope, Escarpment, NE Region									
Starting	Ending								
Year	Year	GMU's in DAU							
1955	1986	12	13	14	17	131			
1987	1988	87	88	89	90	95	951		
1989	2002	87	88	89	90	94	95	951	

DAU A-2, Antelope, Hardpan, NE Region									
Starting	Ending								
Year	Year	GMU's in DAU							
1955	1984	22	23	24	28	29	30		
1985	1986	22	23	24	28	29			
1987	2002	99	100						

The above report is useful as a record of what GMUs are part of what DAU's through time. Note that the summary shows the GMUs in the DAU as a function of year. For pronghorn, a major conversion was made between 1986 and 1987. Prior to 1987, pronghorn GMUs were not numbered the same as deer and elk GMUs. In 1987, a standardized numbering of GMUs was established for all 3 species, mainly to simplify harvest regulations. As a result, the GMU numbers in DEAMAN change dramatically between 1986 and 1987, although the actual DAU management areas are the same.

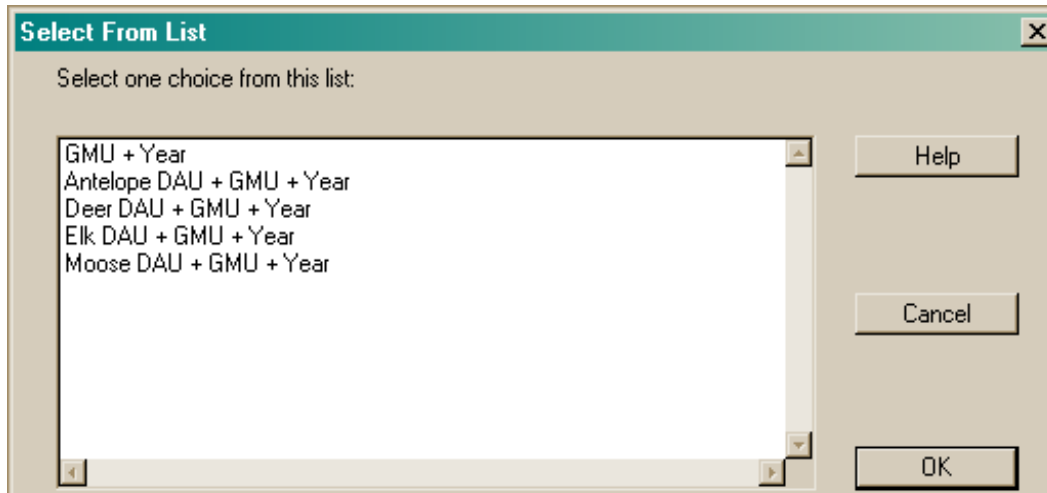
Updating the GMU Database

Just as DAUs change with time, so do the GMUs. The following menu choices lead to procedures to manipulate or check the GMU database.



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The “Browse GMU Database” allows you to change which DAU each GMU is associated with. This process is a bit tricky because of the history of the GMU must be maintained within the database for compatibility with the existing data on harvest, age and sex ratios, and population estimates. When you select to browse the GMU database, you are asked what order you want the records to appear.



The first ordering or index lists the file by GMU, whereas the last 4 orderings lists the GMU file by the species-specific DAU. Which order you select will depend on what you want to do in the file browser when it is opened up. I will select the first ordering for the example to follow. When you click this entry, and then the “OK” button, you are asked to create a filter with the usual window. Just clicking “OK” in the filter creation window results in all the GMU records going into the file browser window. Below is an example of the first 7 GMUs.

Browse Database: GMU						
GMU	DEERDAU	ELKDAU	ANTDAU	MOOSEDAU	YEAR_STRT	YEAR_END
1	D-1	E-47	A-11		1955	2050
2	D-1	E-1	A-11		1955	2050
3	D-2	E-2	A-9		1955	2050
4	D-2	E-2	A-21		1955	1986
4	D-2	E-2	A-9		1987	2050
5	D-2	E-2	A-10		1955	1986
5	D-2	E-2	A-9		1987	2050
6	D-3	E-3	A-3	M-1	1955	2050
7	D-4	E-4	A-3	M-2	1955	1986
7	D-4	E-4	A-33	M-2	1987	1988
7	D-4	E-4	A-36	M-2	1989	2050

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Note that multiple entries exist for several of the GMUs because the GMU was shifted between DAUs. For example, GMU 7 started out in A-3 in 1955, but was changed to A-33 in 1987 because of the renaming of pronghorn GMUs. However, in 1989, the new GMU 7 was changed from A-33 to A-36, and has remained in that DAU since.

Several other menu choices are available under the GMU menu. The "Produce a Report of the GMU Database" generates a summary of the GMU database in a memo window, as shown to the right. This report is basically the same information as shown in the file browser example above.

The "Verify All DAU's in GMU Database Exist" menu choice just checks that the entries in the deer, elk, antelope, and moose DAU fields in the GMU database are defined in the DAU

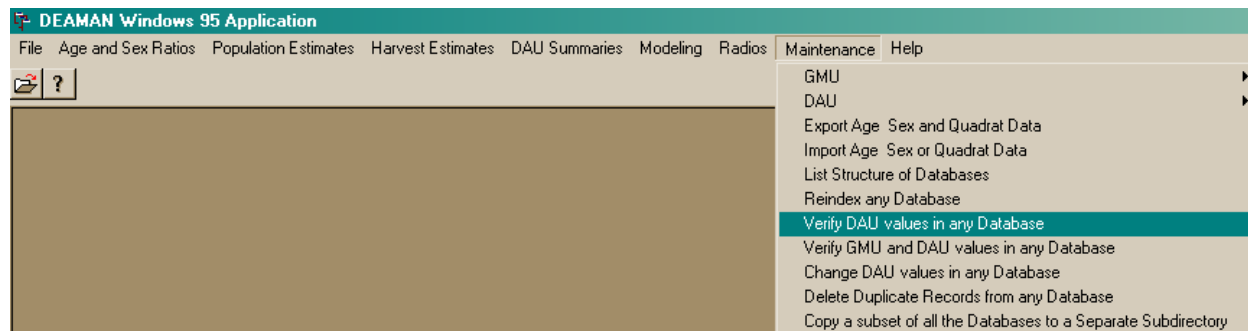
database. Occasionally, you'll make a mistake entering a DAU in the GMU database, and the value will not exist in the DAU database. Running this procedure whenever you make changes in the GMU database is a good idea to uncover problems immediately rather than latter.

The "Compare GMU Database with a Second Copy" is useful when one person has updated his/her GMU database, and you now want to see what is different compared to your copy. This menu choice generates a report in a memo window of what the differences are between the two copies of the GMU.DBF files.

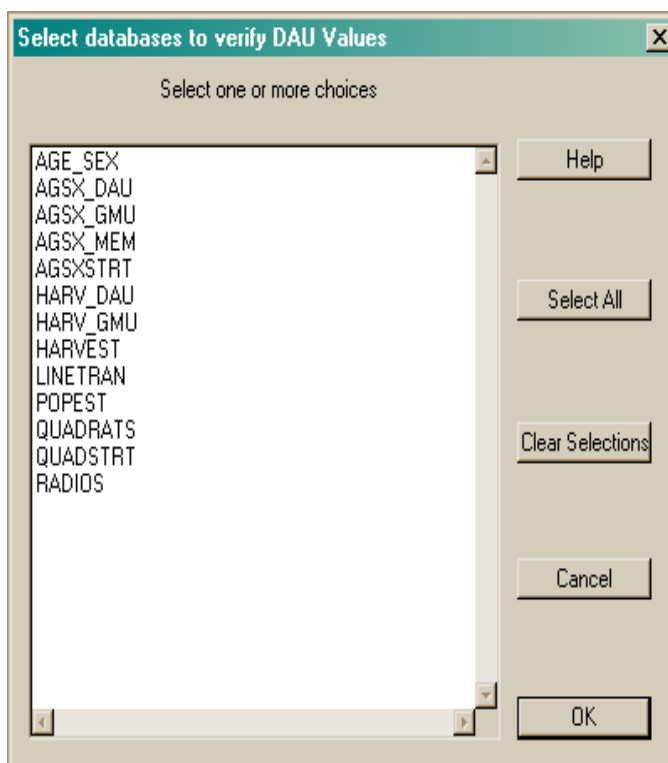
Verifying the DAU and GMU Entries in Databases

A more vexing problem than keeping the DAU and GMU databases up to date is keeping the records in the age and sex and harvest databases up to date. To uncover problems, the menu choice "View DAU values in any Database" is available (highlighted in the display below) to check the entries in any database against the DAU.DBF file.

Summary of DAU's for each GMU in Database						
Page						1
GMU	Start Year	End Year	Deer DAU	Elk DAU	Antelope DAU	Moose DAU
1	1955	2050	D-1	E-47	A-11	
2	1955	2050	D-1	E-1	A-11	
3	1955	2050	D-2	E-2	A-9	
4	1955	1986	D-2	E-2	A-21	
	1987	2050	D-2	E-2	A-9	
5	1955	1986	D-2	E-2	A-10	
	1987	2050	D-2	E-2	A-9	
6	1955	2050	D-3	E-3	A-3	M-1
7	1955	1986	D-4	E-4	A-3	M-2
	1987	1988	D-4	E-4	A-33	M-2
	1989	2050	D-4	E-4	A-36	M-2



When you select this menu choice, you are given a list of databases that can be checked, as shown to the right. You can click on one or more of these databases to have their DAU entries checked. After you've made your selection (possibly with the "Select All" button), you can click "OK" to generate a report in the usual memo window to view the results.



An example is shown to the right for the HARVEST file. There are entries in this file that are incorrect, i.e., "A-" and "D-". In the case of antelope, the "A-" values

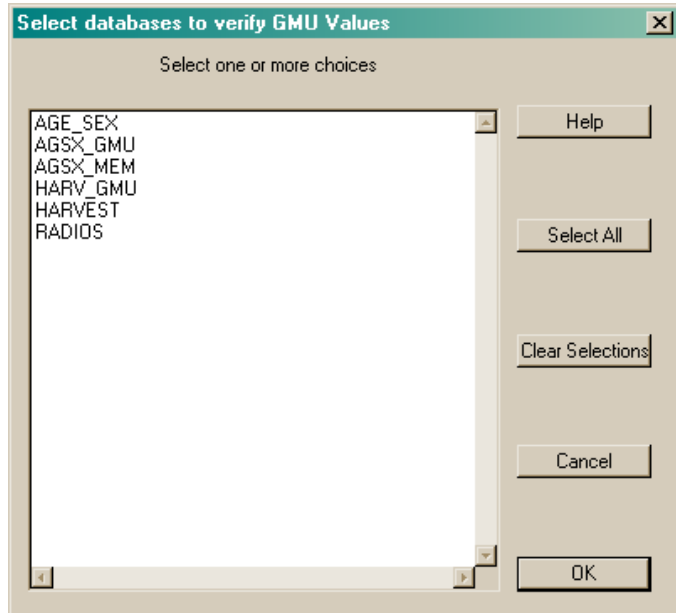
have resulted because animals are harvested in GMUs that do not have an associated DAU, so that the harvest estimation program generates the dummy code of "A-". The "D-" values are caused by some other error that I don't now about.

Problem with database HARVEST.	
DAU	Problem
A-	DAU not in DAU database
D-	DAU not in DAU database

The other more useful menu choice shown below the highlighted choice above is to check the GMU entries in a data file. Because of the changes of GMUs between DAUs, these

values are much more likely to result in errors. When this menu choice is selected, a dialog window requesting which data files you want to check is shown, with an example below.

Note that the number of databases is less than for the similar list for checking the DAU above. This is because fewer databases in DEAMAN include the GMU field, i.e., not all of the data files include GMU level data, whereas every data file in DEAMAN has data associated with a DAU. When I select the AGE_SEX file, I receive the list of errors shown below. Most of these are old errors, probably caused by the change in antelope GMU names. However, the errors with elk units are more recent, and suggest problems that need to be fixed. In particular, GMUs 72 and 73 are evidently associated with the wrong DAU in the AGE_SEX database.

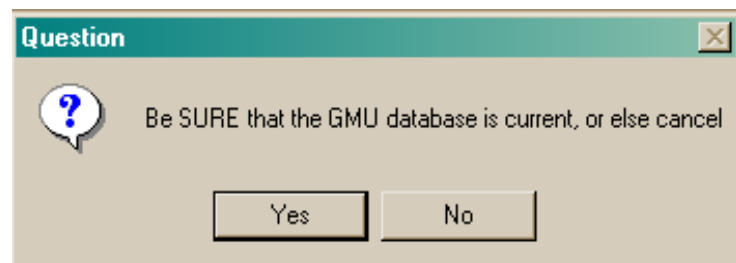


Problem with database AGE_SEX.			
GMU	YEAR	DAU	Problem
128	1986	A-7	GMU not in GMU database
133	1986	A-7	GMU not in GMU database
134	1986	A-7	GMU not in GMU database
135	1986	A-7	GMU not in GMU database
140	1986	A-7	GMU not in GMU database
141	1986	A-7	GMU not in GMU database
142	1986	A-7	GMU not in GMU database
147	1986	A-7	GMU not in GMU database
68	2001	A-14	DAU should be A-15
681	2001	A-14	DAU should be A-15
140	1982	D-32	GMU not in GMU database
140	1983	D-32	GMU not in GMU database
140	1984	D-32	GMU not in GMU database
140	1985	D-32	GMU not in GMU database
140	1986	D-32	GMU not in GMU database
861	1983	E-27	GMU not in GMU database
861	1985	E-27	GMU not in GMU database
861	1986	E-27	GMU not in GMU database
861	1987	E-27	GMU not in GMU database
861	1988	E-27	GMU not in GMU database
861	1989	E-27	GMU not in GMU database
861	1990	E-27	GMU not in GMU database
72	1999	E-29	DAU should be E-24
73	1998	E-29	DAU should be E-24
73	1999	E-29	DAU should be E-24

Changing a GMU from One DAU to Another in Databases

These changes can be made with the “Change DAU Values in Any Database” menu choice under the Maintenance menu. You will be asked to select one or more databases for modification by being provided with a list of databases (the same list as for the verification of GMU entries

above). After you select from this list, you will get a warning message asking you to be sure that your GMU and DAU databases are up to date, so that you don't introduce more errors rather than fix existing errors. An example of this cautionary message is shown above to the right.



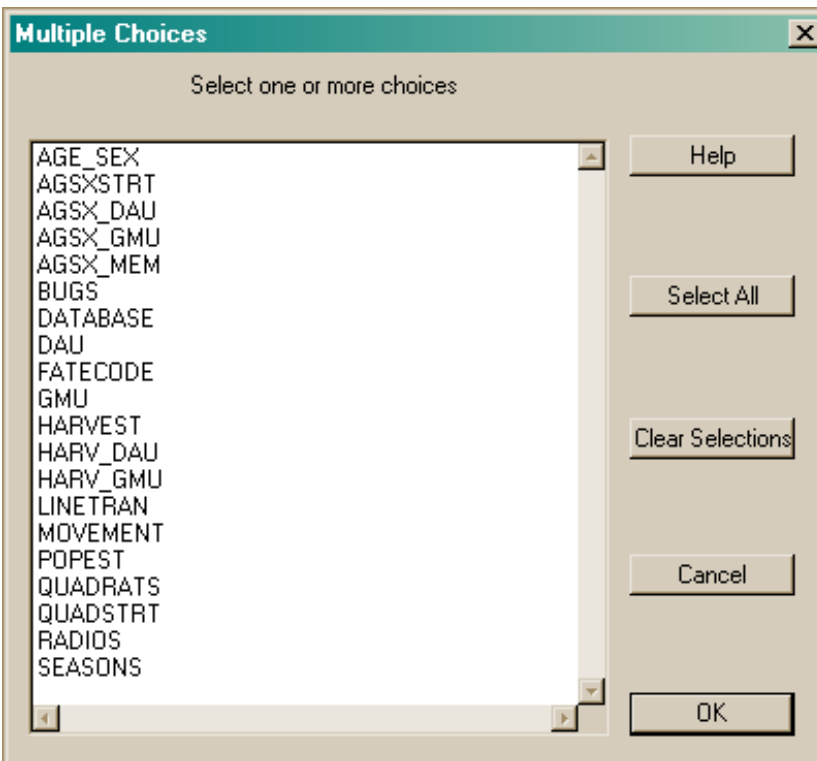
When you select “Yes”, you will get a progress window, and eventually a memo window that lists the changes made to the file. I made changes to the AGE_SEX file, and to the right are a partial list of the changes made. As noted above, these were the GMU and DAU conflicts found, and all have been fixed (assuming that the GMU and DAU files correctly list the GMUs in each DAU).

Deleting Duplicate Records from Databases

One of the common problems in DEAMAN is that the biologist responsible for a GMU changes the DAU that it is part of in his/her copy of the GMU database. However, nobody else around the state makes the change. As a result, when the set of data is exported, and imported into other copies of DEAMAN with incorrect GMU files, errors are noted. Some users will then run the “Change DAU Values in Any Database” procedure to fix these errors. Later, the GMU database is updated, and then the same data are imported. Now, the “Change DAU Values in Any Database” is run again, to fix the old records that were in error, with new records just imported appearing as different entries. When all the records are updated, duplicate records result. The purpose of the procedure to be described next is to remove these duplicate records.

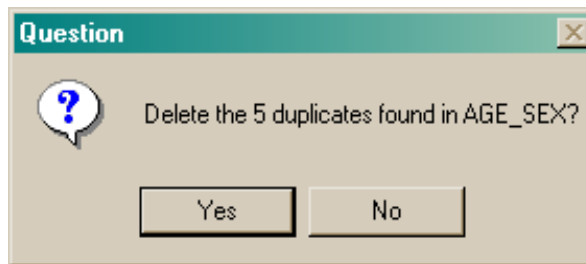
Another way that duplicate records get put into data files is when the index file is corrupted, and data are entered. Then, you check to find the data, and nothing appears. In frustration, you re-enter the data, and this time remember to reindex your files. The result is duplicate records (assuming you entered the data the same both times). These duplicates should be removed, because they affect the precision of the reported estimates, i.e., your results appear to be more precise than they really are.

To delete duplicate records, you select the “Delete Duplicate Records from any Database” choice from under the Maintenance menu. The



screen display to the right shows the list of databases provided to select from. Care must be taken here. You probably don't want to delete duplicates from the LINETRAN database just because it is possible that 2 groups of animals of exactly the same size at exactly the same distance might be recorded (although unlikely). However, the rest of the databases probably should never have duplicate records. I will select the AGE_SEX database as an example, and then click "OK" to proceed.

A progress window appears to show the progress of the process. When completed, you will receive a message asking if you really want to delete any duplicate records. An example is shown to the right. Clicking "Yes" results in the duplicate records being removed, again with a progress window showing you that something is happening.



Tip: You should probably routinely run the procedure to delete duplicate records from your files, just to keep them up to date. When you delete duplicate records from the AGE_SEX file, you will then need to run the age and sex ratio update program to update the AGSX_GMU and AGSX_DAU files with the correct estimates and confidence intervals. You might want to examine the duplicate records before deleting them if there are a lot reported as duplicates.

Listing Structure of the Databases

Often, I want to know the exact structure of a database in DEAMAN, i.e., what the type of each field in the database is (e.g., Character, Numerical, Memo), the length of the field, the number of decimal places sorted in the data, etc. In addition, I may want to see what indexes are available.

```
Structure of database AGSX_DAU (13 fields)
Number of records in the database is 3758.
Field      Type  Length  No. Dec.
DAU         C      5
YEAR        C      4
COUNT_TYPE C      4
R_YM        N      8      2
SE_R_YM     N      8      2
R_2YM       N      8      2
SE_R_2YM    N      8      2
R_AM        N      8      2
SE_R_AM     N      8      2
R_TM        N      8      2
SE_R_TM     N      8      2
R_J         N      8      2
SE_R_J      N      8      2

2 Index Files
AGSX_DAU: DAUORDER(DAU)+YEAR+COUNT_TYPE
AGSX_DAU: DAUORDER(DAU)+COUNT_TYPE+YEAR
```

The “List Structure of Databases” selection under the Maintenance menu provides a means of determining this information. When this menu choice is selected, you are asked to select one or more databases. After you select them, and click “OK” the structure is summarized in a memo window, as shown above for the AGSX_DAU database. Note that the first part of the display is the list of variables in the database, with their type, length, and number of decimals. The last part of the display shows the 2 indexes available for the AGSX_DAU database.

Creating a Subset of the Databases

A old option that is available under the Maintenance menu is “Copy a Subset of All the Databases to a Separate Subdirectory”. This option was useful for creating a set of databases for a specific CDOW region back when hard disks were small, and users did not want a state-wide set of databases. However, with improvements in computer speed and hard disk size, this option has little use today.

Where to From Here

The DEAMAN system was design for the days when computers were not connected, except by a human carrying a disk with data. Today's computer systems are a far cry from that conception. The plan is to have DEAMAN converted to run on the CDOW network, with a central database where each terrestrial biologist will be able to enter data, and then view his/her work relative to all the state-wide data available. But, don't hold your breath – this plan will probably take at least 5 years to implement, if then.

Acknowledgments

Jim Lipscomb and Len Carpenter provided the support and encouragement to initiate the DEAMAN project back in 1984. Bruce Gill kept the funding available through the years to continue the development of the system. Dave Freddy provided encouragement to keep putting in new tools. The CDOW Terrestrial Biologists bore the brunt of the software, particularly the bugs that were sometimes hard to eliminate. Special thanks to Chuck Wagner and Van Graham for being the “sacrificial lambs”.

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Appendix I

Reproduction of

Bowden, D. C., Anderson, A. E., and Medin, D. E. 1984. Sampling plans for mule deer sex and age ratios. *Journal of Wildlife Management* 48:500-509.

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SAMPLING PLANS FOR MULE DEER SEX AND AGE RATIOS

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Abstract: Validity of models for sample observations from each of two sampling plans for estimating fawn : doe and buck : doe ratios of Rocky Mountain mule deer (*Odocoileus hemionus hemionus*) are examined. Standard-error formulas useful for binomial random variables can give misleading results when applied to fawn : doe ratios. Standard-ratio estimators with route and quadrat sampling plans yielded nearly identical estimates of buck : doe and fawn : doe ratios. However, for equivalent levels of precision, route counts were more efficient.

J. WILDL. MANAGE. 48(2):500-509

Management of mule deer is routinely dependent on sample ratios of sex and age to: (1) estimate the proportion of bucks, does, and fawns to assess the effects of sport hunting regulations on a population (Connolly 1981b:261), and (2) provide an index of fawn production and survival (Connolly 1981a:294-298). Sex and age ratios are also the basic data for the change-in-ratio method of estimating the abundance of many vertebrate populations, including deer (Hanson 1963, Paulik and Robson 1969, Seber 1982). Based on computer simulations, Caughley (1974:562) concluded that age ratios of wildlife populations "cannot be interpreted without a knowledge of rate of increase, and if we have an estimate of this rate we do not need age ratios." He conceded (p. 562), however, that a "sudden change in an age ratio . . . indicates that something has happened—but more information is needed to find out what has happened." Since an estimate of the rate of increase requires annual population estimates (Connolly 1981a:301) and most wildlife management agencies do not invest in such esti-

mates, the more easily obtained age (fawn : doe) ratios, cautiously interpreted, provide a useful index of the dynamics of mule deer populations.

Despite widespread use of sex and age ratios in the management of mule deer, the associated sampling variation, sample size requirements, and statistical measures of reliability have received little specific study. Published exceptions include estimates of sample size requirements (Leopold et al. 1951:108, Robinette et al. 1977: 79) and procedures for calculating approximate confidence limits (Riney 1956). Random sampling plans for estimating sex and age ratios of North American deer have not been published.

The objectives of our study were to: (1) present an example of sex and age ratio estimates with relevant standard errors for a mule deer population, (2) examine assumptions or models for sample observations which permit development of measures of reliability of estimates of sex and age ratios, and (3) present implementable random sampling plans for sex and age ratio estimates of deer populations.

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ENVIRONMENT AND SAMPLE POPULATION

Fieldwork was done on a 647.5-km² portion of mule deer winter range within the Cache la Poudre River drainage, Roosevelt National Forest, on the east slope of the Front Range in north-central Colorado. The Cache la Poudre River flows easterly through the Front Range, a generally rugged, often precipitous region characterized by massive granitic outcrops and dendritic drainage patterns. That portion of winter range sampled extended from the eastern edge of the Front Range from about 1,646 to 2,896 m elevation.

Mountain shrub and ponderosa pine-Douglas-fir (*Pinus ponderosa*-*Pseudotsuga menziesii*) plant communities characterize the lower and upper elevational limits, respectively, of the Cache la Poudre winter range (Costello 1954). Mountain park, quaking aspen (*Populus tremuloides*), and big sagebrush (*Artemisia tridentata*) communities occur at higher elevations within the ponderosa pine-Douglas-fir vegetation zone. Selected abiotic and biotic factors of the Cache la Poudre winter range and apparent responses of mule deer to those factors have been characterized by Loveless (1967) and Anderson et al. (1972a,b,c).

The mule deer population is largely migratory. No estimates of the total population of wintering deer are available, but average deer pellet group-derived densities on three representative portions of the Cache la Poudre winter range varied from 10.8 to 23.9 deer/km², 1962-65 (Anderson et al. 1972c).

METHODS

Timing of Surveys

An important consideration in collecting age and sex ratio data is the time of year that counts are conducted. Dasman and Taber (1956) reported that comparison is often a necessary basis for distinguishing sex and age-classes and that counts are most accurate in seasons when deer are in family groups and no single class is unusually conspicuous or retiring.

As an aid in identifying the best sampling period, two counts were made each year (1962-65), one in late November through December (count 1) and one in January (count 2). Year labels, 1962-64, used with count 1 and count 2 will be the year in which count 1 of the pair began. Year labels, 1974-75, refer to the year in which the count began. A late November to early January period was used in 1974 and 1975.

Classification of Deer

Classifications of deer were made using 8 × 40 or 9 × 35 binoculars and 20× spotting scopes. Deer were classified as fawn, doe, buck, or unidentified by groups of one or more on the basis of relative body size, presence or absence of antlers, and applicable criteria listed by Dasman and Taber (1956). A group was identified by observing the joint behavior and spatial distribution of deer. Before each count, each of two observers independently classified the same deer from as many groups of deer as required to consistently obtain identical classifications. The number of groups so classified ranged from about 10 to 40. The 1962-65 counts were made by the same two observers (A.E.A., D.E.M.) and subsequent counts by A.E.A. and five different observers.

Parameters of Interest

Results of analyses are applicable to both fawn : doe and buck : doe ratios. We define F as the number of fawns and D as the number of does in the population at a specified time. The stated ratio of interest is $R_F = F/D$. Consider instead $P_F = F/(F + D)$. Then $R_F = P_F/(1 - P_F)$. Thus, the estimation problem is to determine the proportion of fawns relative to does and fawns. Estimates of P_F and the corresponding estimated standard error can be converted to estimates of R_F and an estimated standard error.

Sampling Plans

Route Counts.—During 1962–65, the deer population was sampled by selecting 10 representative areas of winter range. A route to be traversed by walking was outlined on aerial photographs and located to classify the maximum number of deer within each representative area. The length of each route (about 8.0–14.5 km) was determined by the distance which could be covered by two observers working together, often with one observer maintaining a vantage point, while the other observer attempted to flush hidden deer into view.

Quadrat Counts.—During 1974–75, the deer winter range was divided on 1:24,000 scale U.S. Geological Survey Topographic Quadrangles into 0.65-km² sampling units, 0.80 km/side. Each sampling unit within eight topographic quadrangles was classified subjectively into a high or low deer density stratum (16 strata). A sample of 106 quadrats was randomly selected. Sampling effort was proportionally allocated according to total number of sampling units per stratum (topographic quadrangle) except that at least two sampling units were chosen from every stratum. Counts began on 22 November and

were concluded on 31 December except for two sampling units which were sampled on 9 January 1975.

Two walking observers classified deer on each selected sampling unit. Each sampling unit was approached and traversed to classify the maximum number of deer. Four sampling units were usually counted beginning at dawn and finishing at dusk each day. Counting sequence of sampling units was arranged so nearby sampling units were counted on the same day to minimize duplicate classification of deer and to allow for efficient use of time.

Route and Quadrat Counts.—Both route and quadrat sampling plans were applied from 28 November 1975 to 6 January 1976. Locations of 12 routes were randomized to facilitate comparison of the fawn : doe and buck : doe ratios obtained by the two procedures, and also determination of sample sizes at desired levels of precision for route counts. Route locations were randomized on topographic quadrangles by delineating each route through as many randomly located quadrats as could be traversed by walking from dawn to dusk. Deer on each route were classified the day before the corresponding quadrat count.

All classifications were made after two stages of sampling. First-stage sampling units were routes or quadrats and second-stage sampling units within first-stage units were groups of deer. In 1974 and 1975, the selection of first-stage units for sampling on a given day was randomized.

Theory

One-stage Sampling.—Finite population sampling theory provides one foundation for developing estimation procedures with measured reliability. In a one-stage sampling plan, this theory proceeds by first establishing a list of the sampling units (a sample frame) comprising

the sampled population. Second, a sample is selected from the sample frame in such a manner that the probability of selecting each sampling unit of the sample frame is known and is non-zero. Assumption of no measurement error is also a part of this basic approach. It is assumed that if the variable of interest is measured on every unit of the sample frame, the parameter of interest would be known. Alternatively stated, if one could sample the entire population, the parameter of interest would be known.

Consider constructing a sample frame at any instant in time whose sampling units are individual deer in the study area. Clearly, such a sampling frame exists only conceptually and in practice is not available to allow rigorous use of random number tables or equivalent procedures. But, one can proceed by making assumptions about how deer are selected by field observation procedures.

The standard assumption is that field sampling procedures select deer in the same manner as a simple random sample without replacement (SRS). Thus, each deer in the sampled population is assumed to have an equal probability of being selected and given that n deer are selected, all possible combinations of n deer are assumed to have an equal probability of being the sample of n selected. Hence, the number of fawns (f) or does (d) in the sample conditioned on the total number of animals observed ($d + f$) is described by the hypergeometric distribution. Further, sample sizes are assumed to be large enough that the binomial distribution can be used as an adequate approximation to the hypergeometric distribution. Then, estimators appropriate for a binomial distribution are used with $\hat{P}_F = f/(f + d)$ and estimated standard error of \hat{P}_F given by $\widehat{SE}(\hat{P}_F) = [\hat{P}_F(1 - \hat{P}_F)/(f + d)]^{1/2}$. However, deer encountered in the field occur in

groups. Unless it is plausible to consider these groups as randomly formed relative to doe and fawn composition, $\widehat{SE}(\hat{P}_F)$ can have a large bias. Consistent doe and fawn pairings within groups would cause $\widehat{SE}(\hat{P}_F)$ to be too large on average.

In consideration of the behavioral dependence on fawn-doe pairs in formation of groups of deer available for observation, a group of deer is a natural alternative to an individual deer as a sampling unit. If the field sampling procedures select groups of deer in the same manner as a simple random sample without replacement from all groups of deer (SRSG), then the standard error formula for a ratio gives a robust estimator for the standard error of \hat{P}_F regardless of the composition of the deer groups. Observers are required to record the number of fawns and does in each group observed for use of the ratio standard error formula. Given the basic data of n pairs of values (f_i, d_i), $i = 1, \dots, n$, write

$$\begin{aligned} r_F &= \sum_{i=1}^n f_i / \left[\sum_{i=1}^n (f_i + d_i) \right] \\ &= f / (f + d) \\ &= \hat{P}_F. \end{aligned}$$

Let $t_i = f_i + d_i$ and $t = t_1 + \dots + t_n$. Then,

$$\begin{aligned} \widehat{SE}(r_F) &= \left[n \left(\sum_{i=1}^n f_i^2 + r_F^2 \sum_{i=1}^n t_i^2 \right. \right. \\ &\quad \left. \left. - 2r_F \sum_{i=1}^n f_i t_i \right) / \right. \\ &\quad \left. t^2(n-1) \right]^{1/2}. \end{aligned}$$

Cochran (1977:65-68) discusses the* robustness of the two standard error formulas. Although his formulas use different symbols, they are equivalent except

Table 1. Comparison of binomial and ratio standard errors for fawn (*f*) to fawn plus does (*d*) and buck (*b*) to buck plus does ratios (1962 count 1), Cache la Poudre drainage winter range, Colorado.

Item	Area										Pooled
	1	2	3	4	5	6	7	8	9	10	
Groups (<i>n</i>)	14	3	4	27	44	20	28	15	26	26	207
<i>f</i> /(<i>f</i> + <i>d</i>)	0.375	0.400	0.368	0.482	0.452	0.397	0.440	0.362	0.398	0.541	0.440
(1) $\widehat{SE}(r_f)$	0.074	0.240	0.049	0.030	0.020	0.038	0.029	0.042	0.027	0.037	0.011
(2) $\widehat{SE}(P_F)$	0.099	0.219	0.111	0.055	0.038	0.062	0.050	0.070	0.054	0.058	0.019
(2) ÷ (1)	1.34	0.91	2.24	1.83	1.95	1.63	1.70	1.68	1.99	1.57	1.73
<i>f</i> + <i>d</i>	24	5	19	83	168	63	100	47	83	74	666
Groups (<i>n</i>)	16	3	5	33	49	27	29	18	29	28	237
<i>b</i> /(<i>b</i> + <i>d</i>)	0.400	0.250	0.077	0.318	0.258	0.269	0.177	0.250	0.286	0.370	0.273
(1) $\widehat{SE}(r_b)$	0.090	0.188	0.097	0.060	0.033	0.076	0.042	0.071	0.057	0.063	0.020
(2) $\widehat{SE}(P_B)$	0.098	0.217	0.074	0.059	0.039	0.062	0.046	0.068	0.054	0.066	0.020
(2) ÷ (1)	1.09	1.15	0.76	0.97	1.18	0.81	1.11	0.96	0.95	1.05	0.98
<i>b</i> + <i>d</i>	25	4	13	63	124	52	68	40	70	54	513

that ours omit the finite population correction factor.

Two-stage Sampling.—The need for a two-stage sampling plan arises because it is generally impractical to traverse every part of a study area to give each deer or group of deer a non-zero probability of being sampled as needed in one-stage sampling. Consider then a two-stage sampling plan where the study area is partitioned into primary units. In the first stage of sampling, a sample of the primary units is obtained according to a finite population sampling plan. Field observations in each selected primary unit form the second stage of sampling. The discussion of the previous section now applies to the field observations within each primary unit. Let a sample of m_i deer groups be observed in the “*i*th” primary unit; the basic data consists of m_i pairs of fawn and doe numbers by sampled group. The total number of groups M_i in the “*i*th” primary unit is unknown. Two different two-stage sampling plans are considered.

Let plan A indicate a first-stage SRS of primary sampling units and a second-stage sample equivalent to a SRSG within each selected primary unit. Let plan B indicate a first-stage stratified random sample of primary units where samples within each stratum are SRS with sample size proportional to the number of primary units in the stratum. Also, let the second-stage sample be equivalent to a SRSG within each selected primary unit. Further, let both plans require that the second-stage sampling rates m_i/M_i are constant for all primary sampling units. Let f_i and d_i be the total number of fawns and does in the m_i groups observed in the “*i*th” sample primary unit. In both plans the standard two-stage estimator of P_F is the same as the first-stage estimators \hat{P}_F or r_F . Also the first-stage standard error formula, $\widehat{SE}(r_F)$ gives a conservative (too large on average)

Table 2. Estimates of fawn (*f*) to fawn plus doe (*d*) ratios (r_f) and standard errors (in parentheses) and buck (*b*) to buck plus doe ratios (r_b) from classifications on 10 routes, Cache la Poudre drainage winter range, Colorado, 1962–64.

Count		Year		
		1962	1963	1964
1	r_f (SE)	0.440 (0.017)	0.424 (0.032)	0.385 (0.012)
	$f + d$	666	363	841
2	r_f (SE)	0.413 (0.009)	0.358 (0.013)	0.366 (0.010)
	$f + d$	984	757	1,008
1	r_b (SE)	0.273 (0.021)	0.315 (0.021)	0.328 (0.024)
	$b + d$	513	305	769
2	r_b (SE)	0.193 (0.020)	0.317 (0.029)	0.262 (0.030)
	$b + d$	716	711	866

estimator of the standard error of r_f . If the sampling rate for primary units is small, say less than 10% of all possible sampling units, this bias should not be important relative to other sampling and measurement errors and will tend to compensate for some departures of actual data collection from assumed plans. Data will be analyzed in the Results section as if it were produced from plan A or plan B with the conservative standard error formula $\widehat{SE}(r_f)$. Differences in m_i/M_i values among primary units could cause bias in the estimator r_f . For instance, if the true ratio of fawns to fawns plus does is greater than P_f where m_i/M_i is greater than average, then r_f would obviously overestimate P_f on average. Thus, field techniques need to minimize changes in expected probability of sampling individual deer groups among sampling units. Randomization of the order in which sets of quadrats (and their corresponding routes) are observed minimizes the effect of factors which would systematically change the second-stage sampling rates over the several weeks of observations.

The data in 1962–64 were obtained on the same 10 routes, hence tests for differences in P_f or P_b values among different count times were adjusted for covariances among the estimated ratios as in Cochran (1977:180–183). The required primary

unit sample size n^* to be within $X\%$ of P_f at the $1 - \gamma$ confidence level was calculated as $n^* = nt^2[\widehat{SE}(r_f)]^2/100^2/X^2r_f^2$ where n is the total number of primary units sampled and t is the $1 - \gamma/2$ quantile of a Student's t distribution with $n - 1$ degrees of freedom. The Bonferroni inequality was used to control the significance level when several pairwise comparisons were made simultaneously.

RESULTS AND DISCUSSION

One-stage Sampling

For 1962 count 1, the ratio of $\widehat{SE}(\hat{P}_f)$ to $\widehat{SE}(r_f)$ was greater than 1.33 for 9 of 10 routes while the median ratio was 1.69 (Table 1). The single ratio < 1 was 0.91 and it occurred on a route where only three deer groups were observed with five total does and fawns. However, for P_b , results consistent with independent grouping of bucks and does were produced, i.e., a median ratio of standard error values of 1.01. Similar results occurred on each of the other counts in 1962–64.

Lack of independence between the number of does and fawns per group can also be examined by testing the hypothesis that the distribution of fawns per group is binomially distributed. Cochran (1936) presented the index of dispersion test which is useful in this regard (cf. also

Table 3. Confidence intervals for differences in pairs of ratios at 95% simultaneous confidence level within a given row.

Count	Ratio	1962 minus 1963		1962 minus 1964		1963 minus 1964	
1	P_F	-0.094	0.114	0.003	0.107	-0.056	0.134
	P_B	-0.112	0.028	-0.139	0.030	-0.099	0.073
2	P_F	0.024	0.085	0.015	0.078	-0.045	0.029
	P_B	-0.233	-0.015	-0.153	0.015	-0.034	0.143

Cochran 1954). Significance tests were performed only for the 1962 and 1963 counts because the uniformity of the rejections at levels $\leq 5\%$ significance clearly indicated an alternative distribution was needed. In all cases, significance resulted from less variation in fawn and doe composition per group than predicted from the binomial distribution.

It should be clear that $\widehat{SE}(r_F)$ should be preferred over $\widehat{SE}(P_F)$ if deer groups are selected by SRSG. However, it is expected that probability of observing and classifying each group of deer is not equal among groups. Rather, it is expected that the probability of sampling a group is a function of location of the group relative to observers and intervening terrain and vegetation, activity of the group, behavior of other groups of deer, weather, time of day, and other unspecified factors. Because first-stage units were selected in a randomized order within the count period in 1974 and 1975, the probability of interest is the expected probability of sampling a group. This expected probability is the average of probabilities of sampling the group over all instants of time that sampling could occur within each count.

The estimator r_F and $\widehat{SE}(r_F)$ may still be appropriate to use if the expected probability of sampling a group of deer is independent of the group's fawn-doe composition. However, bias in the regular ratio estimator would be expected to occur, if for a given group size, groups with higher doe composition than other groups had a higher or lower expected probability of being sampled. Classification error where a fawn is identified as a doe or vice versa would introduce similar bias problems.

In route sampling in 1962-64, deer outside of the 10 subjectively selected, representative areas had zero probability of being sampled. Thus, from a strict finite population sampling theory approach, the sample frame consisted of only those deer in the representative areas at the time of the counts. Statistical inference to the deer population of the study area then depends on assumptions which relate the observations in the representative areas to the entire study area. Obviously if one assumes the sample of groups is a SRSG from the entire study area, then r_F and $\widehat{SE}(r_F)$ could be applied to the pooled sample of groups from all routes for each count time in 1962-64. A test of equality of ratios among

Table 4. Confidence intervals for differences of count 1 minus count 2 ratios by year at individual 95% confidence level.

Ratio	Year					
	1962		1963	1964		
P_F	-0.011	0.066	0.011	0.122	0.000	0.038
P_B	0.036	0.125	0.070	0.066	-0.018	0.149

Table 5. Estimates of fawn (*f*) to fawn plus doe (*d*) ratios (r_f), buck (*b*) to buck plus doe ratios (r_b), standard errors, and confidence intervals for differences between strata and sample types, Cache la Poudre drainage winter range, Colorado, 1974 and 1975.

Year and sample	Item	r_f (SE)	<i>f</i> + <i>d</i>	r_b (SE)	<i>b</i> + <i>d</i>	<i>n</i>
1974 quadrats	High density	0.310 (0.019)	478	0.111 (0.018)	371	50
	Low density	0.372 (0.028)	183	0.233 (0.032)	148	56
	95% C.I., high, low combined	(-0.131, 0.007)		(-0.040, -0.185)		
		0.327 (0.016)	661	0.143 (0.018)	519	106
1975 quadrats	High density	0.347 (0.029)	150	0.155 (0.042)	116	33
	Low density	0.424 (0.076)	33	0.296 (0.094)	27	25
	95% C.I., high, low combined	(-0.245, 0.090)		(-0.353, 0.071)		
		0.361 (0.027)	183	0.182 (0.035)	143	58
1975 routes		0.344 (0.012)	716	0.136 (0.023)	544	12
	95% C.I. combined, quadrats minus routes	(-0.050, 0.084)		(-0.040, 0.131)		

routes should be accepted if the SRSG assumption is appropriate.

Significant differences for P_F among routes were noted for the first two count times in 1962 ($P < 0.025$) and 1963 ($P < 0.01$), but the other four tests were non-significant ($P > 0.1$). Although a pooled sample of groups of deer for four of the counts may possibly be used, the simple assumption for analysis does not appear appropriate for all counts. For analysis purposes, it is assumed that the 10 representative areas behave as a SRS of all areas available for sampling, i.e., data were obtained according to plan A.

Two-stage Sampling

A test of equality of the three P_F values for count 1, 1962–64 was performed by constructing simultaneous confidence intervals for the three pairs of difference of the P_F values (Tables 2, 3). The 1962 P_F was larger ($P < 0.05$) than the 1964 P_F . The same procedure for count 2, 1962–64 P_F values (Tables 2, 3) gave larger ($P < 0.05$) values for 1962 P_F than 1963 and 1964 P_F values.

Tests for differences ($P \leq 0.05$) in P_F of count 1 and count 2 yearly pairs (Table 4) gave count 1 1962 P_F greater than count

Table 6. Number of randomly selected quadrats and routes to be within X% of the proportion of fawns (P_F) or proportion of bucks (P_B) at the $1 - \gamma$ confidence level, Cache la Poudre drainage winter range, Colorado, 1974–75.

P_F 1974–75 ^a				P_B 1974–75 ^a			
Confidence level ($1 - \gamma$)				Confidence level ($1 - \gamma$)			
X%	95	90	80	X%	95	90	80
05	410	289	175	05	2,538	1,787	1,083
10	103	73	44	10	635	447	271
20	26	18	11	20	159	112	68
P_F 1975–76 ^b				P_B 1975–76 ^b			
05	23	16	10	05	505	356	217
10	6	4	3	10	127	89	55
20	2	1	1	20	32	23	14

^a Based on results from 106 0.648-km² quadrats.

^b Based on results from 12 all-day, randomly located, walking routes.

2 P_F and in 1963 count 1 P_F greater than count 2 P_F . For similar P_B tests (Table 4), only count 1 P_B was greater than count 2 P_B .

A difference between high and low deer density strata in P_F values for 1974 (Table 5) is indicated only at the 10% significance level. The estimated P_F value for 1975 (Table 5) was also higher in low density quadrats than in high density quadrats, but no significant difference is indicated. P_B was larger ($P < 0.01$) on low density strata than on high density strata in 1974. Although \hat{P}_B on low density quadrats was also greater in 1975 than \hat{P}_B on high density quadrats (nearly twice), the difference was not significant. However, the 1975 sample size was reduced by one-half over 1974.

Comparison of the proportion of fawns (P_F) recorded on route counts in 1975 to route counts in 1962–64 resulted in the 1975 ratio being less ($P < 0.05$) than four of six of the earlier ratios. The exceptions were count 2, 1963 and count 2, 1964.

Comparisons of Estimates Obtained by the Route and Quadrat Sampling Plans

Comparisons of the 1975 estimates of P_F and P_B between the route and quadrat sampling plans do not indicate any significant differences. Route estimates ($\pm SE$) for P_F and P_B were 0.3436 (± 0.012) and 0.1360 (± 0.023), respectively, while quadrat estimates were 0.3607 (± 0.027) and 0.1818 (± 0.035), respectively (Table 5).

Sample sizes or number of quadrats (1974) and routes (1975) required to be within $X\%$ of P_F or P_B at the $1 - \gamma$ confidence level were calculated (Table 6). For quadrats, only 1974 calculations are reported due to the larger sample sizes available for estimating the variance used in the sample size calculation.

Even though route counts and quadrat counts yielded 780 and 258 deer, respectively, their P_F and P_B estimates were nearly identical. However, standard errors of the quadrat estimates were somewhat larger than route estimates. Of the two sampling plans, randomly located route counts appear to be superior because P_F can be estimated at fairly high levels of precision in far less time. The P_B estimate may present an intractable sampling problem in some habitats if a level of precision greater than within $\pm 20\%$ of the true values at $1 - \gamma > 0.80$ is desired.

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Appendix II

Reproduction of

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PRECISION OF HARVEST ESTIMATES OBTAINED FROM INCOMPLETE RESPONSES

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Abstract: Surveys of license holders are typically used to estimate wildlife harvests; however, they often are hampered by return of forms with incomplete information. Thus, I developed estimators that incorporate information from incomplete responses from harvest surveys when only 1 animal may be harvested per license, although the approach can be extended to >1 animal. I developed maximum likelihood estimators and associated variances from multinomial distributions based on conditional binomial processes. Estimators are derived for single classification schemes, such as harvest for subareas within the total area for which a license type is valid, or age and sex categories for the total area (adult females, male young, female young), or double classifications such as combinations of both age/sex and subareas. Hypothetical examples are presented for single and double classification surveys. My estimators incorporate information from incomplete responses to improve precision and hence improve efficiency of harvest surveys.

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Wildlife managers typically estimate harvest by surveying license holders after the close of a season (e.g., Geissler 1990). A sample of license holders is contacted, and information on their success, and age, sex, and area of kill, if any, are requested. The survey form generally consists of a series of questions: Did you hunt with your license? If so, in what area did you hunt? Were you successful in harvesting an animal in this area? If so, what was the age and sex of the animal harvested? Unfortunately, hunters often return survey forms with incomplete information. If the response contains no information, the license holder can be treated as a non-respondent and can be eliminated from the survey. However, often the response contains partial information; the license holder only reports harvesting an animal, but does not provide the age or sex, or the area of the kill, etc.

Herein, I consider the statistical problem of estimating precision of harvest estimates when incomplete responses are included in the sample. I hypothesized that partial responses should not be eliminated from the survey as if they were non-responses, and that proper estimation required using the partial information by making a correction to the usual variance estimator.

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ANALYTICAL METHODS

My methods are applicable to the situation where a license is valid only for taking a single

animal. I first consider the case where the survey results are only classified by 1 variable. For example, the license is only valid for 1 age and sex class, or the survey is only used to estimate total harvest and the manager is interested in estimating the harvest by subareas within the total area for which the license was valid. A second example of a single classification would be the estimation of the harvest of each age and sex class for the total area, ignoring subareas. I then extend these results to the case where 2 classifications are included in the response. For example, the manager is interested in estimating the harvest of each age and sex class for each subarea.

Single Classifications

Because only 1 animal can be harvested per license, I used the binomial distribution to model the probability process. Procedures for surveys with complete information are described by Scheaffer et al. (1986). I extend this method by using conditional binomials to form a multinomial distribution. Did the license holder hunt? If so, did he harvest an animal? If so, was the subarea the area of interest? I first develop the basic notation used to derive the estimators for a single classification. In the interest of clarity, I assume the license is only valid for a single age and sex category (i.e., antlered deer only). I am interested in estimating the harvest for a particular subarea within the total area for which the license is valid. I define the following notation as:

N —Number of licenses sold in the survey (i.e., size of the statistical population to be sampled).

n —Number of license holders surveyed who responded with at least partial information.

n' —Number of license holders surveyed that reported harvesting an animal.

h_i —Number of license holders in the survey that reported harvesting an animal in the subarea of interest, i .

h_o —Number of license holders in the survey that reported harvesting an animal in other subareas.

h_u —Number of license holders in the survey that did not report the subarea in which they harvested an animal (unknown subareas). Note $n' = h_i + h_o + h_u$.

\hat{H}_i —Estimated total number of animals harvested in the subarea of interest, i .

To develop the multinomial model to estimate the number of animals harvested in subarea i , the following probabilities are needed:

p_i —Probability that a license holder harvested an animal in the subarea of interest.

p_h —Probability that a license holder harvested an animal.

p_r —Probability that a license holder reported the subarea where the animal was harvested.

In the following development, I assume these probabilities are independent; the probability that the hunter kills an animal is independent of whether the subarea is reported. A violation of this assumption could occur when hunters have high success in "secret" spots and do not report the subarea. These probabilities are used to form a multinomial distribution with 4 cells: 1) observed h_i with probability $p_i p_r$, 2) observed h_o with probability $(p_h - p_i) p_r$, 3) observed h_u with probability $(1 - p_r) p_h$, and 4) observed $n - n'$ with probability $(1 - p_h)$. The sum of the cell probabilities is 1, and the sum of the observed cells is n . The likelihood (\mathcal{L}) is then proportional to

$\log \mathcal{L}$

$$\propto h_i \log(p_i p_r) + h_o \log[(p_h - p_i) p_r] + h_u \log[(1 - p_r) p_h] + (n - n') \log(1 - p_h)$$

where \log is the natural logarithm function. Maximum likelihood estimation procedures (Mood et al. 1974) (algebraic manipulations performed with the DERIVE computer program [Soft Warehouse, Inc. 1989]) were used to obtain the estimators and associated variances of the 3 unknown parameters (p_i , p_h , and p_r):

$$\hat{p}_i = \frac{h_i n'}{n(h_i + h_o)},$$

$$\widehat{\text{Var}}(\hat{p}_i) = \frac{\hat{p}_i [\hat{p}_h - \hat{p}_i (1 + \hat{p}_h \hat{p}_r - \hat{p}_r)]}{h_i + h_o},$$

$$\hat{p}_r = \frac{h_i + h_o}{n'},$$

$$\widehat{\text{Var}}(\hat{p}_r) = \frac{\hat{p}_r (1 - \hat{p}_r)}{n'},$$

$$\hat{p}_h = \frac{n'}{n},$$

$$\widehat{\text{Var}}(\hat{p}_h) = \frac{\hat{p}_h (1 - \hat{p}_h)}{n}, \quad \text{and}$$

$$\widehat{\text{Cov}}(\hat{p}_i, \hat{p}_h) = \frac{\hat{p}_i (1 - \hat{p}_h)}{n}.$$

All remaining covariances equal zero. The estimator of harvest for the subarea of interest and its variance corrected for a finite population size is

$$\hat{H}_i = N \hat{p}_i \quad \text{with}$$

$$\widehat{\text{Var}}(\hat{H}_i) = N(N - n) \widehat{\text{Var}}(\hat{p}_i).$$

This estimator is only defined for $h_i + h_o > 0$.

The above estimators also can be used to determine the number of hunters in the subarea of interest (i.e., hunting pressure) if hunters are only allowed to hunt in 1 subarea. For this case, probabilities p_i , p_h , and p_r represent hunted in subarea of interest, hunted in a different subarea than the one of interest, or did not report which subarea hunted (but did hunt), respectively, with observed values h_i , h_o , and h_u defined accordingly. Approximate hunting pressure could be estimated if hunters specified the subarea hunted most, even if they hunted in > 1 subarea.

The same estimators are appropriate for estimating harvest of age and sex classes for the total area. For this case, p_i , p_h , and p_r represent the probability that a hunter harvested an animal of the age and sex class of interest, harvested an animal of a different age and sex class, or did not report age and sex class of the animal harvested, respectively. Again, observed values h_i , h_o , and h_u are defined accordingly.

Double Classifications

Under this scenario, estimates of harvest are desired for each age and sex class for each sub-

Table 1. Observed quantities and cell probabilities for a 10-cell multinomial distribution used to model the double classification scenario of survey results.

Cell	Observed value ^a	Cell probability
1	h_{ij} animals of age and sex class i harvested in subarea j	$p_1 p_2 p_3 p_4 p_h$
2	h_{oj} animals of other age and sex classes harvested in subarea j	$(1 - p_1) p_2 p_3 p_4 p_h$
3	h_{uj} animals unknown age and sex class harvested in subarea j	$p_2 (1 - p_3) p_4 p_h$
4	h_{io} animals of age and sex class i harvested in other subareas	$p_1 (1 - p_2) p_3 p_4 p_h$
5	h_{oo} animals of other age and sex classes harvested in other subareas	$(1 - p_1) (1 - p_2) p_3 p_4 p_h$
6	h_{uo} animals unknown age and sex class harvested in other subareas	$(1 - p_2) (1 - p_3) p_4 p_h$
7	h_{iu} animals of age and sex class i harvested in unknown subareas	$p_1 p_3 (1 - p_4) p_h$
8	h_{ou} animals of other age and sex classes harvested in unknown subareas	$(1 - p_1) p_3 (1 - p_4) p_h$
9	h_{uu} animals unknown age and sex class harvested in unknown subareas	$(1 - p_3) (1 - p_4) p_h$
10	$n - h_i - h_o - h_u$	$(1 - p_h)$

^a Symbols are defined in the text.

area. Animals harvested are classified uniquely according to age and sex (i.e., adult females, male young, or female young). I define the additional notation as:

h_{ij} —Number of animals of the age and sex class of interest (i) reported harvested in the subarea of interest (j).

h_{oj} —Number of animals other (o) than the age and sex class of interest reported harvested in the subarea of interest (j).

h_{uj} —Number of animals of unknown (u) age and sex class reported harvested in the subarea of interest (j).

$h_{.j}$ —Total number of animals reported harvested in subarea j . Note that $h_{.j} = h_{ij} + h_{oj} + h_{uj}$.

h_{io} —Number of animals of age and sex class i reported harvested in other (o) subareas than the one of interest.

h_{oo} —Number of animals other (o) than the age and sex class of interest reported harvested in other (o) subareas.

h_{uo} —Number of animals of unknown (u) age and sex class reported harvested in other (o) subareas.

$h_{.o}$ —Total number of animals reported harvested in other (o) subareas. Note that $h_{.o} = h_{io} + h_{oo} + h_{uo}$.

h_{iu} —Number of animals of the age and sex class of interest (i) reported harvested in unknown (u) subareas.

h_{ou} —Number of animals other (o) than the age and sex class of interest reported harvested in unknown (u) subareas.

h_{uu} —Number of animals of unknown (u) age and sex class reported harvested in unknown (u) subareas.

$h_{.u}$ —Total number of animals reported harvested in unknown (u) subareas. Note that $h_{.u} = h_{iu} + h_{ou} + h_{uu}$.

\hat{H}_{ij} —estimated total number of animals of the age and sex class of interest (i) harvested in the subarea of interest, j .

I now develop a multinomial model to estimate H_{ij} . The unknown parameters to be estimated are:

p_1 —Probability that a license holder harvested an animal of age and sex of interest, given that an animal was harvested.

p_2 —Probability that a license holder harvested an animal in the subarea of interest, given that an animal was harvested.

p_3 —Probability that a license holder reported the age and sex of animal harvested, given that an animal was harvested.

p_4 —Probability that a license holder reported the subarea where an animal was harvested, given that an animal was harvested.

p_h —Probability that a license holder harvested an animal.

With these probabilities defined, I can define 10 cells of a multinomial distribution (Table 1). From the method of maximum likelihood, resulting estimators and variances are:

$$\hat{p}_1 = \frac{h_{ij} + h_{io} + h_{iu}}{h_{ij} + h_{io} + h_{iu} + h_{oj} + h_{oo} + h_{ou}},$$

$$\widehat{\text{Var}}(\hat{p}_1) = \frac{\hat{p}_1(1 - \hat{p}_1)}{h_{ij} + h_{io} + h_{iu} + h_{oj} + h_{oo} + h_{ou}}$$

Table 2. Hypothetical harvest data from a survey to estimate number of antlerless deer hunters and harvests in a subarea for the double classification scenario of survey results.

Subarea of reported harvest	Age and sex of harvest			
	Adult females	Male young	Female young	Unknown kill
In subarea of interest	25	3	4	2
In other (known) subareas in the survey	250	31	42	23
Unidentified subarea	2	1	0	30

$$\hat{p}_2 = \frac{h_{ij}}{h_{ij} + h_{io}},$$

$$\widehat{\text{Var}}(\hat{p}_2) = \frac{\hat{p}_2(1 - \hat{p}_2)}{(h_{ij} + h_{io})},$$

$$\hat{p}_3 = \frac{(h_{ij} + h_{io} + h_{iu} + h_{oj} + h_{oo} + h_{ou})}{(h_{ij} + h_{io} + h_{iu})},$$

$$\widehat{\text{Var}}(\hat{p}_3) = \frac{\hat{p}_3(1 - \hat{p}_3)}{(h_{ij} + h_{io} + h_{iu})},$$

$$\hat{p}_4 = \frac{h_{ij} + h_{io}}{h_{ij} + h_{io} + h_{iu}},$$

$$\widehat{\text{Var}}(\hat{p}_4) = \frac{\hat{p}_4(1 - \hat{p}_4)}{(h_{ij} + h_{io} + h_{iu})},$$

$$\hat{p}_h = \frac{h_{ij} + h_{io} + h_{iu}}{n},$$

$$\widehat{\text{Var}}(\hat{p}_h) = \frac{\hat{p}_h(1 - \hat{p}_h)}{n},$$

with all covariances equal to zero.

The estimate of harvest of age and sex class i in subarea j is

$$\hat{H}_{ij} = N\hat{p}_i\hat{p}_j\hat{p}_h,$$

with the variance corrected for finite population size

$$\widehat{\text{Var}}(\hat{H}_{ij}) = N(N - n)\widehat{\text{Var}}(\hat{p}_i\hat{p}_j\hat{p}_h),$$

where

$$\begin{aligned}\widehat{\text{Var}}(\hat{p}_i\hat{p}_j\hat{p}_h) &= \hat{p}_i^2\hat{p}_j^2\widehat{\text{Var}}(\hat{p}_1) + \hat{p}_i^2\hat{p}_h^2\widehat{\text{Var}}(\hat{p}_2) \\ &\quad + \hat{p}_j^2\hat{p}_h^2\widehat{\text{Var}}(\hat{p}_3).\end{aligned}$$

These estimators are only defined for $h_{ij} > 0$.

ANALYTICAL RESULTS

I now present a hypothetical example of the application of these procedures to estimate number of deer hunters for the subarea of in-

terest, total harvest of antlerless animals for the area of interest, total number of adult females harvested on all subareas, and number of adult females harvested in the area of interest. In the example, $N = 25,000$ licenses sold, with a sample of $n = 2,500$. Of these 2,500, only $n' = 2,000$ actually hunted, and only 1,800 knew or reported where they hunted. Of these 1,800, $h_i = 200$ of them hunted in the subarea of interest. Consequently, h_o is 1,600, and h_u is 200.

The estimate of probability of hunting in the subarea of interest is then

$$\begin{aligned}\hat{p}_i &= (200 \times 2,000) / [(200 + 1,600) \times 2,500] \\ &= 0.08889,\end{aligned}$$

with remaining parameters estimated as

$$\begin{aligned}\hat{p}_r &= (200 + 1,600) / 2,000 = 0.9, \quad \text{and} \\ \hat{p}_h &= 2,000 / 2,500 = 0.8.\end{aligned}$$

The estimated variance of \hat{p}_i is

$$\begin{aligned}\widehat{\text{Var}}(\hat{p}_i) &= 0.08889[0.8 - 0.08889 \cdot \\ &\quad (0.8 \times 0.9 + 1 - 0.9)] \\ &\quad \div (2,500 \times 0.8 \times 0.9) \\ &= 0.0000359.\end{aligned}$$

The estimate of number of hunters in the unit of interest is

$$\hat{H}_i = 25,000 \times 0.08889 = 2,222,$$

with a variance of

$$\begin{aligned}\widehat{\text{Var}}(\hat{H}_i) &= 25,000(25,000 - 2,500)0.0000359 \\ &= 20,197.535.\end{aligned}$$

Then, a 95% confidence interval is constructed as $\hat{H}_i \pm 1.96 \text{Var}(\hat{H}_i)^{1/2}$, giving an interval of (1,944, 2,501), or $\pm 12.5\%$.

To compute the total harvest in the subarea of interest, the data (Table 2) are summarized as

$$h_i = (25 + 3 + 4 + 2) = 34,$$

$$h_o = (250 + 31 + 42 + 23) = 346,$$

$$h_u = (2 + 1 + 0 + 30) = 33, \text{ so that}$$

$$n' = 34 + 346 + 33 = 413.$$

Then, the estimate of the probability of harvesting an animal in the subarea of interest is

$$\begin{aligned} \hat{p}_i &= (34 \times 413) / [(34 + 346) \times 2,500] \\ &= 0.01478, \end{aligned}$$

with the other parameters estimated as

$$\hat{p}_r = (34 + 346) / 413 = 0.92,$$

$$\hat{p}_h = 0.1652.$$

The estimated variance of \hat{p}_i is

$$\begin{aligned} \widehat{\text{Var}}(\hat{p}_i) &= \{0.01478[0.1652 \\ &\quad - 0.01478(0.1652 \times 0.92 \\ &\quad + 1 - 0.92)]\} \\ &\quad \div (2,500 \times 0.1652 \times 0.92) \\ &= 0.0000063. \end{aligned}$$

The estimated harvest in the subarea of interest is

$$\hat{H}_i = 25,000 \times 0.01478 = 1,045,$$

with variance

$$\begin{aligned} \widehat{\text{Var}}(\hat{H}_i) &= 25,000(25,000 - 2,500)0.0000063 \\ &= 3,539.90 \end{aligned}$$

giving a 95% confidence interval of (928, 1,161), or $\pm 11.2\%$.

Next, I consider the application of this estimator to determine the total number of adult females killed in the survey. In this case,

$$h_i = 25 + 250 + 2 = 277,$$

$$h_o = 7 + 73 + 1 = 81,$$

$$h_u = 2 + 23 + 30 = 55, \text{ and}$$

$$n' = 277 + 81 + 55 = 413.$$

Then,

$$\hat{p}_i = (277 \times 413) / [(277 + 81)2,500] = 0.1278,$$

$$\hat{p}_r = (277 + 81) / 413 = 0.8668, \text{ and}$$

$$\hat{p}_h = 0.1652.$$

The estimated variance of \hat{p}_i is

$$\widehat{\text{Var}}(\hat{p}_i) = \{0.1278[0.1652$$

$$\begin{aligned} &\quad - 0.1278(0.1652 \times 0.8668 \\ &\quad + 1 - 0.8668)]\} \end{aligned}$$

$$\div (2,500 \times 0.1652 \times 0.8668)$$

$$= 0.0000464.$$

The estimated harvest in the subarea of interest is

$$\hat{H}_i = 25,000 \times 0.1278 = 3,196,$$

with estimated variance

$$\begin{aligned} \widehat{\text{Var}}(\hat{H}_i) &= 25,000(25,000 - 2,500)0.0000464 \\ &= 26,083.56 \end{aligned}$$

giving a 95% confidence interval of (2,779, 3,512), or $\pm 9.9\%$.

Last, I consider the estimate of the harvest of adult females in the area of interest. The probability of killing an adult female is estimated as

$$\begin{aligned} \hat{p}_1 &= (25 + 250 + 2) \\ &\quad \div (25 + 250 + 2 + 7 + 73 + 1) \\ &= 0.7737 \end{aligned}$$

$$\hat{p}_2 = 34 / (34 + 346) = 0.08947,$$

$$\begin{aligned} \hat{p}_3 &= (25 + 250 + 2 + 7 + 73 + 1) \\ &\quad \div (34 + 346 + 33) \\ &= 0.8668, \end{aligned}$$

$$\begin{aligned} \hat{p}_4 &= (34 + 346) / (34 + 346 + 33) \\ &= 0.92, \text{ and} \end{aligned}$$

$$\hat{p}_h = (34 + 346 + 33) / 2,500 = 0.1652.$$

Then, to compute the variance of harvest,

$$\begin{aligned} \widehat{\text{Var}}(\hat{p}_1) &= [0.7737(1 - 0.7737)] \\ &\quad \div (25 + 250 + 2 + 7 + 73 + 1) \\ &= 0.000489, \\ \widehat{\text{Var}}(\hat{p}_2) &= [0.08947(1 - 0.08947)] / (34 + 346) \end{aligned}$$

$$= 0.000214,$$

$$\begin{aligned} \widehat{\text{Var}}(\hat{p}_h) &= [0.1652(1 - 0.1652)] / 2,500 \\ &= 0.0000562, \end{aligned}$$

so that

$$\widehat{\text{Var}}(\hat{p}_1 \hat{p}_2 \hat{p}_h) = 0.08947^2 \times 0.1652^2 \times 0.000489$$

$$\begin{aligned}
 &+ 0.7737^2 \times 0.1652^2 \times 0.000214 \\
 &+ 0.7737^2 \times 0.08947^2 \\
 &\times 0.0000562 \\
 &= 0.0000039
 \end{aligned}$$

The estimated harvest of adult females is

$$\begin{aligned}
 \hat{H}_y &= 25,000 \times 0.7737 \times 0.08947 \times 0.1652 \\
 &= 286,
 \end{aligned}$$

with estimated variance

$$\begin{aligned}
 \widehat{\text{Var}}(\hat{H}_y) &= 25,000(25,000 - 2,500)0.0000039 \\
 &= 2,179.15
 \end{aligned}$$

and with a 95% confidence interval of (194.5, 377.5), or $\pm 32\%$.

DISCUSSION

Several potential biases exist for the estimators presented here. The model for the double classification scenario uses information from other subareas and from unknown subareas to allocate unknown age and sex class harvest into known age and sex class estimates. Alternatively, models could be developed to not use the unknown subareas, or not use both the unknown and other subareas, to make this allocation. I have chosen to use all the available information to make this allocation, although differences between age and sex ratios among subareas may make the information inappropriate. However, I assume that the subareas making up the total legal area for the license type would be homogeneous, or else distinct license types would have been issued.

A second potential bias may exist if license holders not reporting the subarea of their kill are less likely to report that they killed an animal of an "undesirable" age and sex class. That is, a hunter killing a fawn may be more prone to just report killing an animal, and not provide the subarea and age and sex class. Such a behavioral trait would result in underestimates of the "undesirable" age and sex classes and overestimates of the "desirable" age and sex classes.

The models used to derive these estimators require that the various probabilities do not vary among license holders, an assumption likely to be violated. For example, heterogeneity of success rates is likely because some hunters are more

experienced and/or possess superior hunting skills. The anticipated impact of this violation of assumptions is that estimators would not be biased, but that variance estimates would be too small. That is, the harvest process is more variable than the model allows, so that the estimates appear overly precise.

Finally, these estimators do not correct for the inherent biases of harvest surveys. Typically, successful big game hunters are more likely to return surveys promptly, while unsuccessful hunters are less likely to respond (H. D. Riffel, Colo. Div. Wildlife, pers. commun.). Barker (1991) demonstrated that nonrespondents to waterfowl harvest surveys may harvest fewer animals and hunt less than respondents. Such biases require more complex consideration than described here, such as time-sequenced methods.

MANAGEMENT IMPLICATIONS

More precise estimates of harvest result from incorporating the information from incomplete responses to harvest surveys. Hence, the survey is more efficient, and a smaller number of hunters need to be surveyed.

This paper only considers the scenario where a single animal is harvested. However, the scheme can be extended to the scenario where a small number of animals can be harvested. For example, if ≤ 3 animals can be harvested, then the probability that a hunter harvested 0, 1, 2, or 3 animals can be computed and used to estimate total harvest.

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Appendix III

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FITTING POPULATION MODELS TO MULTIPLE SOURCES OF OBSERVED DATA

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Abstract: The use of population models based on several sources of data to set harvest levels is a standard procedure most western states use for management of mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*), and other game populations. We present a model-fitting procedure to estimate model parameters from multiple sources of observed data using weighted least squares and model selection based on Akaike's Information Criterion. The procedure is relatively simple to implement with modern spreadsheet software. We illustrate such an implementation using an example mule deer population. Typical data required include age and sex ratios, antlered and antlerless harvest, and population size. Estimates of young and adult survival are highly desirable. Although annual estimates are desirable, the procedure also can be applied—with less precision—to data sets with missing values in any of the data series. The model-fitting procedure adjusts input estimates and provides estimates of unobserved parameters to achieve the best overall fit of the model to observed data. Rigorous, objective procedures such as those described here are required as a basis for wildlife management decisions because diverse stakeholder groups are increasing the intensity with which they scrutinize such management decisions.

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Key words: AIC, Akaike's Information Criterion, *Cervus elaphus*, elk, least squares, maximum likelihood, model fitting, mule deer, *Odocoileus hemionus*, parameter estimation, population modeling, spreadsheet software.

Modeling populations to set harvest levels and other management strategies has become the norm in wildlife management (Bartholow 1992, White 2000). For example, the Colorado Division of Wildlife builds or modifies such models annually for each of the data analysis units (DAU) in the state. The division uses these models to project the population and determine harvest objectives for the upcoming hunting season. To develop these models, data are collected on the DAU population (White and Bartmann 1998a, Bowden et al. 2000). In Colorado, measured attributes have included young:female and male:female ratios, either pre-harvest or postharvest (Czaplewski et al. 1983, Bowden et al. 1984, Pojar et al. 1995); harvest (White 1993, Steinert et al. 1994); survival with radiocollars (White et al. 1987, Bartmann et al. 1992, White and Bartmann 1998b); neckbands (White and Bartmann 1983) or mortality transects (Bartmann 1984, Bartmann and Bowden 1984); population size from quadrat counts (Kufeld et al. 1980, Bartmann et al. 1986, Pojar et al. 1995); mark-resight (Bartmann et al. 1987, Bear et al. 1989, Neal et al. 1993, Bowden and Kufeld 1995); line transects (White et al. 1989, Pojar et al. 1995); change-in-ratio (Otis 1973), catch-effort (Laake 1992), and pellet group counts (Bowden et al. 1969, Freddy and Bowden 1983a,b).

Typically, biologists who build models based on data collected from a DAU population align or otherwise match the model predictions to the observed values manually in an ad hoc and subjective fashion. They do this by changing model parameters until the predictions match some prior expectations or visually appear to approximate the data (e.g., Bartholow 1992). However, this actually is a statistical parameter estimation problem and more formal solution methods are available. We describe a statistically rigorous, objective, yet relatively easy-to-implement procedure for estimating parameters of population models from multiple types of population data. We use a mule deer example from the Piceance Basin in northwest Colorado, USA, to illustrate the procedure. Despite the emphasis on game management, the technique generally is applicable to fitting any wildlife population model to multiple types and sources of data. More mechanistic models that relate population responses to environmental or management variables also can be fit with this approach, although data requirements for such applications are higher.

METHODS

Data Collection

Age and sex ratios for the Piceance Basin mule deer population were estimated with helicopter surveys conducted during December or early Jan-

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uary prior to antler drop each biological year from 1981 to 1997 (except 1987 and 1996). Estimates were based on $\bar{x} = 1,041$ deer classified/year (SD = 249, min = 759, max = 1,539). Survival estimates for 1981–1995 (White et al. 1987, Bartmann et al. 1992, White and Bartmann 1998b, Unsworth et al. 1999) of fawns were based on $\bar{x} = 106$ collars/year (SD = 45, min = 45, max = 161), and survival estimates of adults were based on $\bar{x} = 51$ collared females/year (SD = 27, min = 8, max = 93). This assumed that survival of males >1 year old was the same as for adult females. We radio-collared deer in November or early December and computed survival for a 1-year interval. We developed estimates of harvest from telephone surveys of 5% of the license holders for over-the-counter antlered licenses, and from 20 to 50% of limited antlerless licenses (Steinert et al. 1994). Population estimates for 1981–1985 and 1988 were developed from 120 0.25-mi² (0.67-km²) quadrats surveyed by helicopter following Kufeld et al. (1980). Surveys were conducted during January or February. We estimated sightability of deer on quadrats as 0.67 following Bartmann et al. (1986), meaning that each deer counted on a quadrat represented 1.5 deer. We will refer to the entire set of direct field estimates for parameters as $\hat{\theta}_i$ (where i references all years and field measurements sequentially) and their estimated standard errors as $SE(\hat{\theta}_i)$.

Population Model

The model must be kept simple to economize the amount of input required to estimate model parameters from observed data. However, the model must adhere to biological authenticity to be useful in projecting population status. For illustration purposes, we develop a model for mule deer to correspond with an example data set. Mule deer population dynamics are much more complicated than the model portrays. However, routine measurement of a wider array of inputs required for a more complicated model is unrealistic. Thus, the model presented here is a reasonable trade-off between what can be measured practically and what is needed to predict mule deer populations for management purposes. Even this simplified model will have more potential parameters than the data can support. Consequently, we compare a family of related models with additional simplifying assumptions and select the most parsimonious using Akaike's Information Criterion (AIC; Burnham and Anderson 1998). We begin by defining the most

general model; reduced parameter variants are described in the section on Model Fitting.

We model the population in annual time steps referenced to the time of annual surveys in December, following harvest. Our model includes only 2 age classes: fawns and adults. We chose to not distinguish yearlings from older animals because survival data were not collected to support this additional complication. The gender of fawns is not differentiated until they are counted in December, at which point a constant proportion, r , is added to adult males. Thus, we define 3 population segments: fawns (labeled Juveniles or J), does (labeled Females, F), and bucks (labeled Males, M). Fawn, female, and male population segments survive the year according to specific annual rates, $S_J(t)$, $S_F(t)$, and $S_M(t)$. New fawns are recruited into the population in December in proportion $R_J(t)$ to each year's December adult female population. Due to harvest and aging, does present in December do not match the does that gave birth, however, we define recruitment relative to the December does to match the age ratio data collected in the field. Annual harvest mortality is modeled separately for males, $H_M(t)$, and females, $H_F(t)$; is additive and independent of natural mortality; and is applied to the population following natural mortality and prior to the next December count. Thus, the equations to project the population from December of year t forward to December of year $t + 1$ after natural mortality, harvest, and recruitment are:

$$\begin{aligned} N_F(t+1) &= r S_J(t) N_J(t) + S_F(t) N_F(t) - H_F(t+1), \\ N_M(t+1) &= r S_J(t) N_J(t) + S_M(t) N_M(t) - H_M(t+1), \\ \text{and} \\ N_J(t+1) &= R_J(t+1) N_F(t+1). \end{aligned} \quad (1)$$

Total population size (N_T) in early December in year t is thus

$$N_T(t) = N_J(t) + N_F(t) + N_M(t). \quad (2)$$

The M:F ratio, $R_M(t)$, is also computed in the model for comparison to values measured in the field

$$R_M(t) = N_M(t) / N_F(t). \quad (3)$$

Because we collected no explicit data on adult male survival, separate annual estimates of male and female survival are not identifiable, so they must be modeled using fewer parameters. One plausible simplifying relationship assumes that

male survival follows the same pattern through time as female survival, $S_M(t) = \gamma S_F(t)$. That is, γ could be included as a parameter to be estimated. Although either a constant recruitment sex ratio, r , or γ could be estimated with our data, estimation of both, or time-specific values of either would require a more elaborate data collection operation. In preliminary model runs, we tested the value of adding sex differences and found it explained a negligible amount of variation. Therefore, we chose to use the simplest model possible by setting $r = 0.5$ and $\gamma = 1$ so that adult male and female natural recruitment and survival rates are equal. Thus, differences between the sizes of the adult sex class are only due to harvest.

For each year, the model contains values for 10 parameters: $N_T(t)$, $N_M(t)$, $N_F(t)$, $N_J(t)$, $H_M(t)$, $H_F(t)$, $S_F(t)$, $S_J(t)$, $R_M(t)$, $R_J(t)$. However, 5 relationships impose biological structure on these parameters given in Equations 1–3, leaving 5 unknowns to be measured each year. In addition to these, adult male and female population size must be measured in at least 1 additional year (typically initial values, $N_M(0)$ and $N_F(0)$) for the model to be identifiable. Thus, for a model of T years, a minimum of $5T + 2$ values must be observed to fit this model. If fewer values were measured than the number of unknowns in the model, additional assumptions to simplify the model would be required.

Model Fitting

It is important to distinguish between the set of estimated model parameters (referred to collectively as $\hat{\theta}_i$) versus estimates made directly from field observations (collectively, $\tilde{\theta}_i$). Of the 10 annual values included in our model, $\hat{\theta}_i$, we collected field data to estimate 6 [$H_M(t)$, $H_F(t)$, $S_F(t)$, $S_J(t)$, $R_M(t)$, and $R_J(t)$] in most years (with occasional missing values) plus measurements of $N_J(t)$ in 6 years. These field estimates constitute the set $\tilde{\theta}_i$. Notice that in this example, more annual field measurements (6) were made than the number of unknowns (5) in the model, providing additional degrees of freedom for statistical estimation.

If, as in our example, all of the unknown parameters in the population model, $\hat{\theta}_i$, can be estimated directly from field data (i.e., by setting $\hat{\theta}_i = \tilde{\theta}_i$), then the population model can be used directly (without fitting) to project the population. The population for the first year is taken as the population estimate from quadrat surveys for the same year multiplied by the sightability factor (Bartmann et al. 1986) of 1.5. Population seg-

ments are then initialized by using estimated age and sex ratios to partition the estimated population. Survival and recruitment rates are then used to project subsequent annual populations. However, this approach does not use all of the population- and age-ratio data after the first year and, thus, is inefficient. Small errors in survival rates can accumulate over time, resulting in large errors (either positive or negative) in the projected population size in later years. This method also requires direct estimates of survival and harvest every year. We make such a projection to demonstrate its poor performance.

Because we have more measurements than unknowns, an improved parameter estimation strategy that uses all of the data is to treat each of the parameters directly estimated from field data, $\tilde{\theta}_i$, as an observation and then select corresponding values for each model parameter, $\hat{\theta}_i$, so that the sum of weighted squared errors between field- and model-based estimates of all parameters

$$\varepsilon_i^2 = [(\tilde{\theta}_i - \hat{\theta}_i) / \text{SE}(\tilde{\theta}_i)]^2 \quad (4)$$

is minimized. The weight of each of the field measurements is taken as the reciprocal of its variance. Each parameter may have been estimated with field measurements but has an associated (often large) error, $\text{SE}(\tilde{\theta}_i)$, and so better estimates can be developed using all of the data. Any change in a model-based estimate from its original field-based estimate increases the size of the error, and thus penalizes the optimization for the change. The resulting fit of the model balances the fit to each of the independently estimated field parameters based on the relative precision of each. By using $\text{SE}(\tilde{\theta}_i)$ to weight the difference $\tilde{\theta}_i - \hat{\theta}_i$, the resulting residual error is approximately a standardized normal variable with mean zero and standard deviation 1. Thus, the varying scales of the observed data are standardized to have the same relative scale. The ε_i can be viewed as a sample of size n from a Normal(0, 1) distribution with joint log likelihood

$$\log \mathcal{L} = -\frac{n}{2} \log(2\pi) - \frac{1}{2} \sum_{i=1}^n \varepsilon_i^2, \quad (5)$$

because σ is assumed to be 1 in the usual normal log likelihood. Hence, σ is not estimated as part of the likelihood. The sample size n is the total number of ε_i^2 summed in the objective function. To maximize the log likelihood function, only the term $\sum_{i=1}^n \varepsilon_i^2$ needs to be optimized, and this process can be done easily with the optimizer

function of spreadsheet software. This estimator is termed an ordinary least squares estimator (OLS; Seber and Wild 1989) because covariances of the ε_i across the different types of field measurements are assumed to be zero.

We fit a family of models to the field measurements using the OLS procedures described above. Models in this series differed only in the amount of temporal (annual) variation allowed for each of the survival and age ratio parameters. Year-specific harvest was assumed to be known— $SE[\hat{H}_i(t)] = 0$; $\hat{H}_i(t) = \bar{H}_i(t)$ —and thus not modified in the model fitting. All models in this series require estimating initial sizes for adult male and female population segments. We first consider Model 1 with constant recruitment and adult and fawn survival across years, with 5 parameters estimated. Next, Model 2 with a linear trend in age ratios, but constant adult and fawn survival is considered, with 6 parameters estimated. Models 3–7 include year-specific estimates for various combinations of the recruitment rate and adult and juvenile survival rates. Each of these models has 15 year-specific fawn survival parameters estimated for the 18-year period (1981–1998) with 3 missing values in each. Like Model 2, Models 4 and 5 assume a linear trend in recruitment. Model 7, the most general, adds 45 year-specific estimates of recruitment and survival to the 2 initial population segment size estimates for a maximum of 47 parameters.

We used model selection based on information theory (Burnham and Anderson 1998) to select among these various models using the AIC_c value

$$AIC_c = -2\log\mathcal{L} + 2K + \frac{2K(K+1)}{n-K-1}, \quad (6)$$

where K is the number of parameters estimated via optimization to minimize $\sum_{i=1}^n \varepsilon_i^2$. Note that $-2\log\mathcal{L}$ is equal to $\sum_{i=1}^n \varepsilon_i^2$ plus a constant, so that only the $\sum_{i=1}^n \varepsilon_i^2$ term needs to be included in the calculation of AIC_c for model selection, which is based only on relative values. Standard errors of parameter estimates can be obtained by inverting the negative of the information matrix of the log likelihood function. The information matrix is the matrix of second partial derivatives of the log likelihood with respect to each of the parameters estimated.

The OLS estimator is not fully efficient (Seber and Wild 1989) because the covariances of the ε_i across the different types of field measurements are incorrectly assumed to be zero. Although serial autocorrelation is not likely to be a problem with the direct field estimates because the surveys

are performed independently across time, the fact that many of the model parameters being estimated are shared across equations and affect several model predictions (e.g., adult survival affects both the population size and age and sex ratios) may induce covariances. The residuals in year i can be considered a vector, $\underline{\varepsilon}_i$, with k elements corresponding to each different type of measurement. The $\underline{\varepsilon}_i$ vectors each can be considered to be a multivariate normal sample with covariance matrix $\underline{\Sigma}$. The log likelihood then becomes

$$\log\mathcal{L} = -\frac{nk}{2}\log(2\pi) - \frac{n}{2}\log(|\underline{\Sigma}|) - \frac{1}{2}\sum_{i=1}^n \underline{\varepsilon}_i' \underline{\Sigma}^{-1} \underline{\varepsilon}_i, \quad (7)$$

where $|\underline{\Sigma}|$ is the determinant of $\underline{\Sigma}$.

Theory for estimating $\underline{\Sigma}$ and fitting such a model (termed seemingly unrelated regressions, SUR) is provided by Gallant (1987), and implemented in PROC MODEL (SAS Institute 1988) only for data sets where measurements for each of the field observations are all taken each year. Gallant (1987) and Seber and Wild (1989) also discuss more elaborate estimators that iteratively estimate $\underline{\Sigma}$ and the parameters being estimated simultaneously, again implemented in PROC MODEL (SAS Institute 1988). The advantage of these more elaborate estimation schemes is to improve efficiency, but this is accomplished at some cost due to the increased number of parameters that must be estimated for the covariances of the field measurements. More importantly, the complexity of these more advanced procedures discourages their adoption for most wildlife management purposes. Note that the OLS estimates are a special case of the SUR estimates with $\underline{\Sigma}$ defined as an identity matrix.

RESULTS

Data collected on the Piceance mule deer herd in northwestern Colorado (Table 1) exhibit high year-to-year variation in fawn survival, and a gradual decline in fawn:doe ratios from 1981 to 1997. In addition, quadrat population estimates demonstrate high sampling variation, i.e., large standard errors. In contrast, standard errors of age and sex ratios are small relative to population estimates, and survival estimates are the most precise of all the estimated parameters.

We first built a naive 2-age class model (fawns, adults) with sex-specific classes for adults from these data using direct field estimates of the parameters (i.e., with no additional model fitting). The initial population was computed as 1.5 times

the 1981 population estimate using the assumption that 67% of the animals were counted on the quadrats sampled due to sightability limitations, based on the work of Bartmann et al. (1986). Age and sex structure of the initial 1981 modeled population was computed from the 1981 age and sex ratios. Years (1987, 1996, 1998) with missing fawn:doe ratios were replaced by the mean of the series (however, these values are not used later for parameter estimation in the model fitting procedure). Although a downward trend exists in the fawn:doe ratios, using the mean value for these years should increase the population size for this model's predictions. Nevertheless, with these inputs, the buck:doe ratio becomes negative and the population declines to zero (Fig. 1). Although the population had been thought to be declining during the 1990s (i.e., see population estimates for a portion of the area modeled here in White and Bartmann 1998b), the decline was not that severe. Sampling variation in the parameter estimates and the resulting inconsistencies cause the model to predict extirpation. Most notably inconsistent are the population estimates for 1981, 1982, and 1983. The 1982 estimated population appears to be much too low, in that biologically the population likely could not grow from the estimated low point in 1982 to the higher estimate in 1983 (Table 1, Fig. 1).

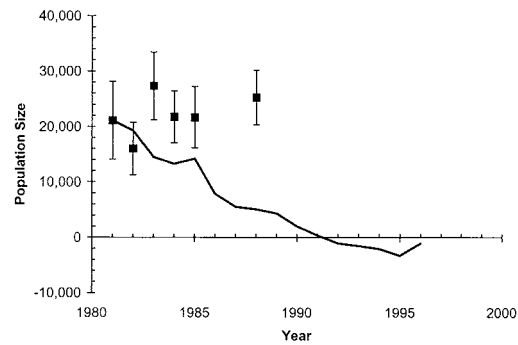


Fig. 1. Estimates and 95% confidence intervals for observable (uncorrected for sightability) mule deer population (squares) based on quadrat counts from helicopter surveys in the Piceance Basin, Colorado, USA, plotted with a naive population projection (line) based on direct field estimates of initial population size by age and sex class and annual survival rates and harvest. Population projections were not fitted to annual age ratio data. Model predictions were multiplied by the sightability factor of 0.67 so that predicted and observed population values are comparable.

Model fitting using the OLS estimation procedure for the series of models indicated that, based on AIC_c , the most appropriate model in this sequence is Model 4, with a linear trend on age ratios, year-specific fawn survival, but constant adult survival (Table 2). The Akaike weight

Table 1. Estimates of fawn and adult survival, fawn:doe and buck:doe ratios, and population size for the Piceance mule deer herd, northwestern Colorado, USA, 1981–1995. Missing data are shown as blank entries.

Year	Fawns:100 does		Bucks:100 does		Fawn survival		Adult survival		Population size		Buck harvest		Doe harvest	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
1981	77.7	5.78	13.8	1.95	0.48	0.068	0.86	0.049	21,103	3,592	2,293		19	
1982	75.5	4.34	11.4	1.34	0.36	0.044	0.81	0.048	16,004	2,425	3,072		10	
1983	78.8	4.83	11.4	1.45	0.05	0.021	0.83	0.045	27,309	3,129	3,512		64	
1984	70.2	4.49	7.4	1.16	0.19	0.039	0.88	0.040	21,723	2,387	2,017		12	
1985	72.5	5.57	7.2	1.38	0.41	0.039	0.92	0.038	21,657	2,822	1,849		30	
1986	63.5	4.11	14.0	1.62	0.42	0.038	0.76	0.068			931		21	
1987					0.15	0.033	0.88	0.083			1,326		24	
1988	74.2	3.76	13.9	2.04	0.35	0.064	0.83	0.108	25,248	2,517	1,449	75	585	19
1989	65.7	2.72	12.4	1.90	0.77	0.049	0.90	0.051			2,227	95	1,512	59
1990	61.2	3.32	16.2	2.09	0.32	0.069	0.94	0.035			1,822	92	1,691	48
1991	46.4	2.26	11.9	1.45	0.49	0.072	0.77	0.052			1,917	92	1,238	45
1992	45.5	2.85	10.5	1.74	0.14	0.029	0.71	0.048			1,310	68	1,296	70
1993	42.6	3.04	10.1	2.30	0.65	0.038	0.84	0.038			1,041	63	777	53
1994	46.1	2.86	7.8	1.67	0.76	0.034	0.88	0.035			1,210	65	221	17
1995	47.6	3.03	10.7	2.24	0.70	0.038	0.93	0.029			1,489	68	182	16
1996											1,631	69	206	18
1997	46.1	3.00	11.5	1.80							1,194	60	442	39
Mean	60.9	3.73	11.3	1.74	0.42	0.045	0.85	0.051	22,174	2,812	1,782	75	490	38
SD	13.7		2.6		0.23		0.07		3,886		698		589	

Table 2. Sequence of models fit to the field measurements reported in Table 1. The number of parameters for each component are included in parentheses.

Model	Age ratios	Fawn survival	Adult survival	Initial population	K ^a	AIC _c ^b
1	Constant (1)	Constant (1)	Constant (1)	Buck & Doe (2)	5	1009.1
2	Linear trend (2)	Constant (1)	Constant (1)	Buck & Doe (2)	6	900.1
3	Constant (1)	Year-specific (15)	Constant (1)	Buck & Doe (2)	19	366.1
4^c	Linear trend (2)	Year-specific (15)	Constant (1)	Buck & Doe (2)	20	203.0
5	Linear trend (2)	Year-specific (15)	Year-specific (15)	Buck & Doe (2)	34	268.3
6	Year-specific (15)	Year-specific (15)	Constant (1)	Buck & Doe (2)	33	227.4
7	Year-specific (15)	Year-specific (15)	Year-specific (15)	Buck & Doe (2)	47	413.3

^a K is the number of estimated parameters in each model.

^b AIC_c is the Akaike Information Criterion calculated as $\sum_{i=1}^n \epsilon_i^2 + 2K + \frac{2K(K+1)}{n-K-1}$ (see text for full definition).

^c Best (lowest AIC_c) model is shown in bold.

for Model 4 is >0.9999, indicating that this model is by far the most appropriate of the 7 considered. Results from Model 4 produce a much more consistent fit of the model to the quadrat estimates of population size (Fig. 2) than the original naive model projection (Fig. 1). The predicted decline in the population is now consistent with other observations of population size estimated on a small portion of the study area modeled here (White and Bartmann 1998b). The fit of the model predictions to the estimated buck:doe ratios is reasonable (Fig. 3) and involves only small adjustments to fawn:doe ratios (Fig. 3) and fawn survival estimates (Fig. 4). Adult survival rates are assumed constant, and thus 14 parameters are saved in this model compared to Model 5, where this rate is year-specific. Modeling the linear trend in recruitment saves an additional 13 parameters relative to the most general model. The strong selection of this model indicates that most of the year-to-year variation in observed adult survival rates is due to sampling error rather than process variation in the actual survival rate. The decline in recruitment also is clearly distinguished from other explanations for the decline in this population.

Two subtle, but critical, differences between the original estimates and those from the best fitted model account for the dramatic differences in predictions. First, adult survival rate in the fitted model is estimated to be 0.88, whereas the geometric mean of the direct field estimates of adult survival rate was 0.85. This small difference is enough to change the projection from population extirpation to a more modest decline. Second, the estimated observable (adjusted for sightability)

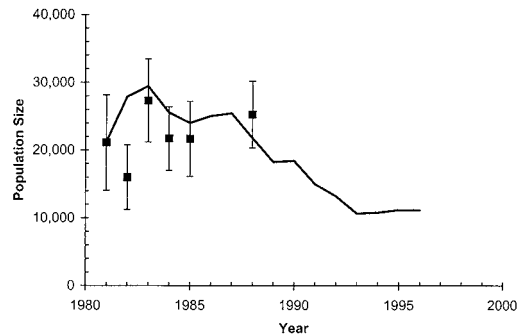


Fig. 2. Estimates and 95% confidence intervals for mule deer population (squares) based on quadrat counts from helicopter surveys in the Piceance Basin, Colorado, USA, plotted with the best (AIC_c) fitted model (Model 4) predictions (line) which include constant adult survival, a linear trend in recruitment, and year-specific juvenile survival rates. Model predictions were multiplied by the sightability factor of 0.67 so that predicted and observed population values are comparable.

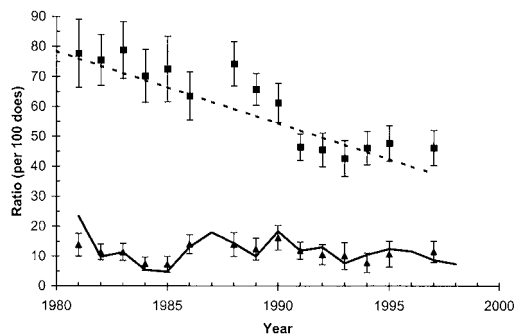


Fig. 3. Estimates and 95% confidence intervals for buck:doe (triangles) and fawn:doe (squares) ratios from helicopter surveys in the Piceance Basin, Colorado, USA, plotted with the best (AIC_c) fitted model (Model 4) predictions (solid and broken lines, respectively) which include constant adult survival, a linear trend in recruitment, and year-specific juvenile survival.

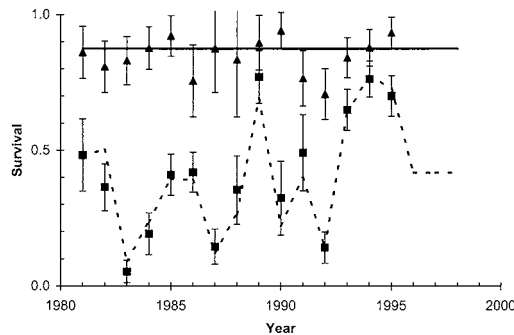


Fig. 4. Radiocollar estimates of fawn (squares) and adult female (triangles) survival rates from the Piceance Basin, Colorado, USA, compared to best (AIC_c) fitted model (Model 4) predictions (broken and solid lines, respectively) which include constant adult survival, a linear trend in recruitment, and year-specific juvenile survival.

starting population in 1981 from the fitted model, based on all available data, is 24,203 as opposed to the 1981 direct field estimate of 21,103.

Excel® Version 5/7 and Quattro Pro® Version 8 spreadsheets with the Piceance mule deer example are available from the Internet at <http://www.cnr.colostate.edu/~gwhite>. Although this spreadsheet model is specific to the example presented here, it can be used as an example from which other population models can be easily implemented by making appropriate changes.

DISCUSSION

The procedure described here for model fitting to observed data is a least squares estimation approach. If the statistical errors in the estimates are assumed to be normally distributed, then the procedure gives maximum likelihood estimates. Because survival estimates from radiocollars might be more appropriately treated as binomial variables, the objective function could be changed for these estimates to be a binomial log-likelihood. In the example presented here, this was not done because the survival estimates were computed with a staggered-entry Kaplan-Meier procedure with some observations that were censored. Therefore, a binomial log-likelihood estimator would not be appropriate.

One extension that should be considered is to incorporate the sampling covariances of estimates taken in the same year. For example, the fawn:doe and buck:doe ratio estimates have a sampling covariance because both are estimated from the same classification data. Other param-

eters might have sampling covariances depending on the estimation approach used, e.g., fawn and adult survival rates would be correlated if estimated from band recoveries (White and Bartmann 1983) instead of radios. An appropriate technique to handle this within-year covariance would be to use matrix algebra to weight the pair of estimates by the inverse of their variance-covariance matrix. Mathematically, the entire optimization process could be formulated as a matrix equation equivalent to the SUR procedure described, although such an elegant presentation would not likely benefit the understanding of the procedure by most biologists, nor would it be likely to change the modeling results enough to alter management decisions in the field.

The procedure presented here is similar to the one described by Lipscomb (1974) where we consider the weights in his nonlinear programming formulation as the inverse of the variance of the estimates. The power of modern spreadsheet software facilitates rapid implementation of this approach, whereas previously, problem-specific software, often written in FORTRAN code at substantial expense, was not as robust and easy to adapt to new problems as the spreadsheet approach. The availability of PROC MODEL (SAS Institute 1988) provides the flexibility to use more elegant estimation procedures, but does not permit missing values, thus requiring that all field measurements be taken every year. Other approaches to population model fitting involving Bayesian and Kalman filtering methods have been suggested (Schnute 1994, Zheng et al. 1998, Miller and Meyer 2000, Trenkel et al. 2000) but are sufficiently complex to discourage most management agencies from adopting them. We believe that the simpler methods outlined here are a sufficient improvement over previously available methods. Relatively small effort is required to apply them, whereas the cost of more advanced techniques may not be justified by the incremental improvement in efficiency.

The applicability of model fitting and selection procedures presented here is not limited to the structure or features of the example mule deer model that we used for illustration. There are no restrictions on linearity, continuity, functional complexity, or parameterization. The structure of the most general model considered should depend on the complexity of the data available, the prior knowledge about the biology of the species, and the research or management questions of interest. With sufficient data, it is a sim-

ple matter to include additional complexity such as additional age classes or separate survival rates by sex. Density feedback from population size to vital rates can be modeled as a simple linear relationship, or using a nonlinear function with a more appropriate shape such as the logit, to enforce biological constraints. Common harvest complexities encountered for some species (e.g., elk), such as wounding losses, illegal kill, and differential harvest mortality due to antler point regulations, can be modeled by constant, proportional, or more complex functions. When precise harvest records are unavailable, unlike in our example, harvest itself can be considered a parameter to be estimated. Our modeling of juvenile survival as a function of time illustrates how all of these additional biological and management mechanisms can be implemented.

One desirable objective of more complex, mechanistic models of a population is their ability to project forecasts of the relevant covariates. The model in our example modeled recruitment as a function of time and adult survival as a constant. Only the fawn survival rate was year-specific. Therefore, population projections can be made using this model by adding additional assumptions only about the future fawn survival rate. Using a mean value is one such assumption that facilitates projections. However, a model that could predict future fawn survival as a function of more easily forecast variables would be an improvement and should be the focus of future research. For example, a particularly valuable class of extended models incorporate explanatory variables into the population dynamics. Covariates can be used to provide estimates of winter severity or drought (McCulloch and Smith 1991). Furthermore, juvenile survival or recruitment might be modeled as a function of commonly available weather covariates such as seasonal temperatures, precipitation, or snow depths. These relationships need not be linear. To accommodate severe winters, an approach that works reasonably well is to compute survival each year as $S_i = sW_i$, where W_i represents a winter severity index with $W_i = 1.0$ representing an average winter, values of $W_i > 1$ are more severe than normal, and $0 \leq W_i < 1$ less severe than normal. The values of s and each W_i are additional parameters that must be estimated to fit the data to the model. The value of such models is that they aid researchers in understanding causes of population change and managers in anticipating the future effects of current and forecast environmental conditions.

Numerical considerations can cause problems with the optimization required to determine the maximum likelihood estimates. Some models require more effort to find the optimal solution than other models. A useful option available with many spreadsheet optimization programs is to allow automatic scaling of the optimization variables. Otherwise, the several orders of magnitude difference of parameters (e.g., survival rates vs. population sizes) will cause numerical difficulties with the optimizer, and no solution will be achieved. When data are sparse (many missing values) or the model is overparameterized, these problems can prevent convergence of the optimization or cause it to converge to a local minima. For difficult models, a good approach is to begin by optimizing only the parameters that have the most variation while fixing the others at the values of the field estimates. In the Piceance mule deer example, we started the optimization process with just the population estimates, holding age ratios, fawn survival, and adult survival constant. After we calculated this intermediate solution, we progressively added the linear trend on age ratios, year-specific fawn and adult survival, and age ratios, to the optimization, using the prior solution as initial values. At each step, all parameters estimated by optimization at the previous step were reestimated simultaneously using the added parameters, so that each solution was globally optimized.

For some problems, particularly ones with sparse or imprecise data, the optimizer can be given numerical constraints on any combination of parameters to ensure that they remain within biologically reasonable limits. This should be done sparingly to avoid biasing results with preconceived notions of the values of parameters. Typically, it should be necessary only to constrain parameters to the range of biologically feasible values, such as $0.0 \leq S \leq 1.0$. If biologically unreasonable results are obtained even with these minimal constraints, this suggests that the data set is inadequate and probably should be abandoned or supplemented with additional data, or the model should be simplified by removing some parameters.

We emphasize that all field estimates are assumed to be unbiased and accompanied by appropriate (and unbiased) measures of precision. Because the estimated precision of each measured value is used to weight that value in the model fitting, parameters with overestimated precision, due to either bias or improper methods of

estimation, will be given greater consideration than they deserve. When such a situation is suspected and cannot be corrected, the suspect data can either be discarded or given less weight by inflating the precision estimate, both of which are ad hoc approaches that we discourage.

In the example presented here, data were available for almost every parameter estimate for most years, with quadrat population estimates being the notable exception. Because our data set was nearly complete, the most general models we could examine included those with annual variation in various vital rates. However, when data are more sparse, as is common, stronger assumptions must be made to simplify models by, for example, considering only average survival or simple trends. Typically, survival estimates from radio-collars are not available for most mule deer DAU in Colorado. Also, many of the mule deer DAU and almost all elk DAU lack field-based estimates of population size, adding another complication to the model-fitting procedure. Model fitting with field estimates of only age and sex ratios, in the absence of survival and population data, often results in driving the population size projections to infinity. Statistically, this is a parameter identifiability problem. Biologically, this behavior is exhibited because the larger the population, the less impact is produced when estimated harvest is subtracted from the model population, allowing more flexibility to fit the observed age and sex ratios. For these DAU, assumptions must be made about the population's size at some point in time. Although no specific minimum data set is required to apply this technique, sparser and less precise data sets require more subjective assumptions, can be expected to yield less precise results, and may even fail to converge on a biologically reasonable solution at all. Caution in the interpretation of such inadequate data sets is strongly advised. Addition of subjective constraints to the optimization process, in such cases, also is strongly discouraged because this will lead to subjective conclusions that are not supported by the data.

MANAGEMENT IMPLICATIONS

The model-fitting procedure presented here provides a rigorous, objective model alignment procedure that is easy to implement with standard PC spreadsheet software. Most wildlife investigations lack the necessary data with which to estimate all the required parameters before a model is built. Even if data are plentiful, inconsistencies in the data will likely cause the perfor-

mance of the model to be unsatisfactory. Thus, a model-fitting procedure is required to decide which estimates to adjust, and by how much, to achieve the best alignment. However, spreadsheet models should be used neither to legitimize subjective opinions nor as a substitute for good field data (see Unsworth et al. 1999 for recommended data requirements). As population models are increasingly used to manage wildlife populations, more rigorous and objective methods should be used to build these models, so that they can withstand the public scrutiny of an increasingly involved and diverse set of stakeholder groups.

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